# Astroparticles in space

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**2. Why going to space?**

The atmosphere

Large scales

Stabilities

**3. Constraints on a space mission**

Format constraints

Environment(s)

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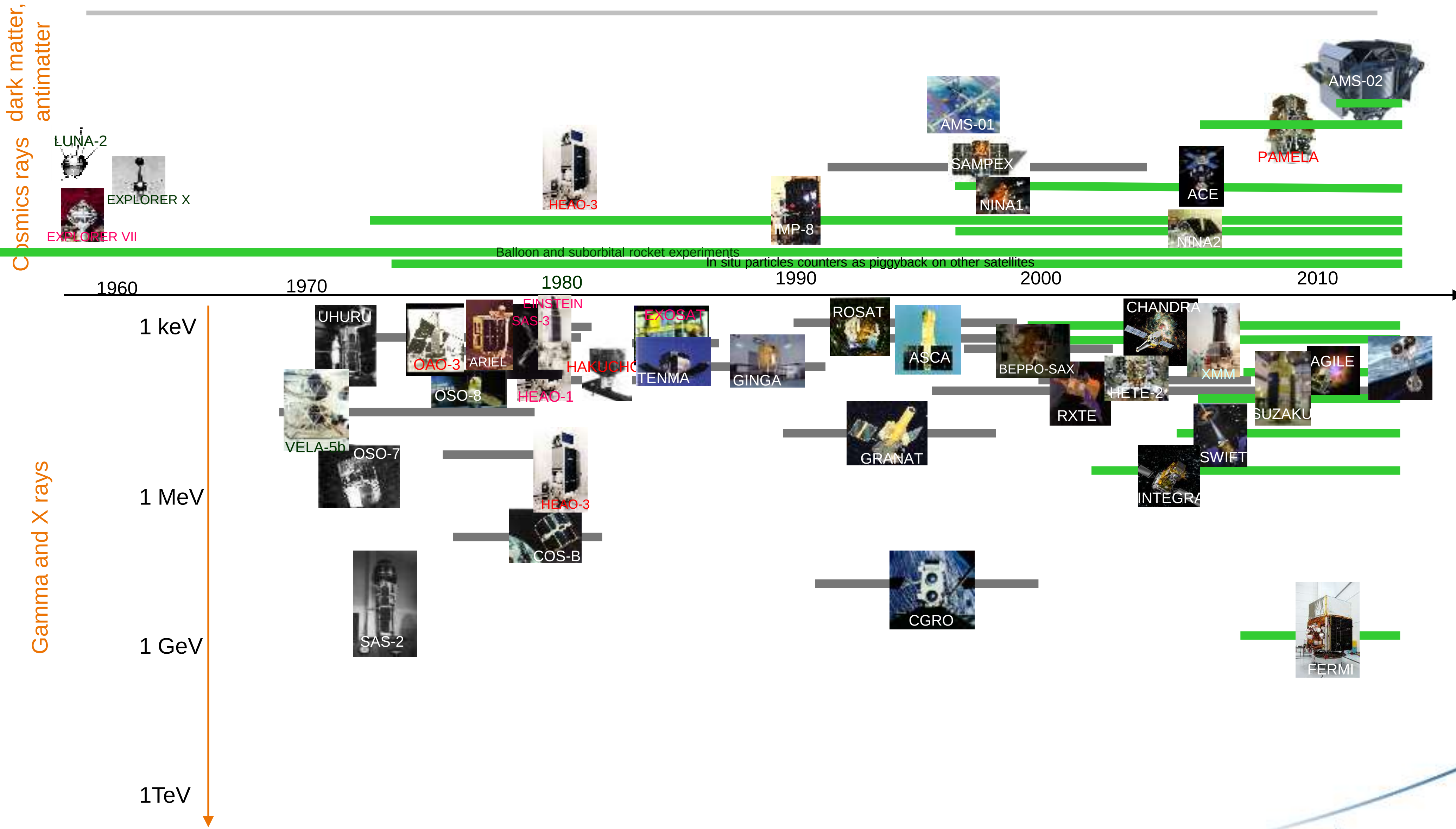
cnes

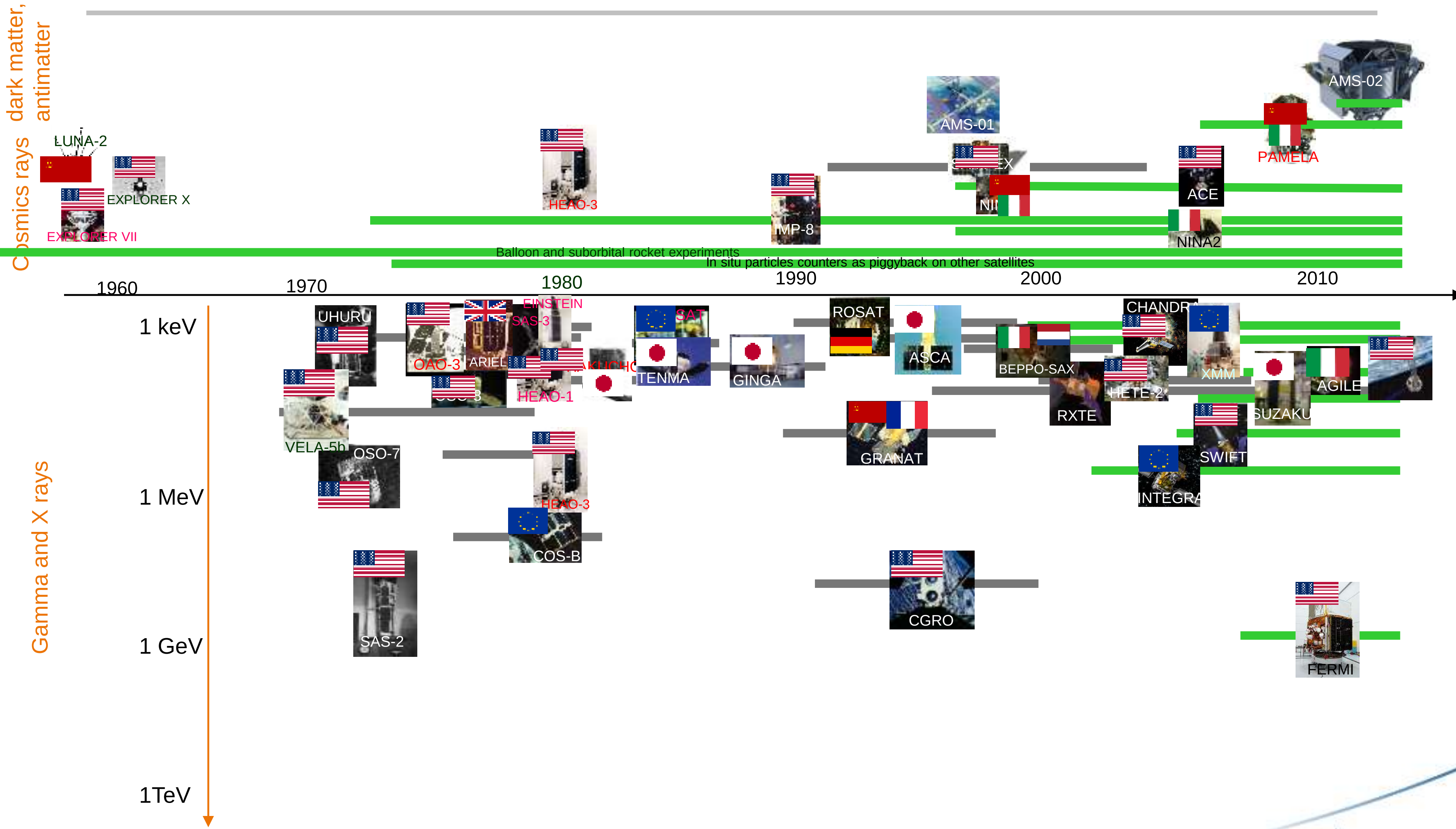
# CNES and science

CNES is the French Space Agency, in charge of proposing and implementing space programs in France.
⇒ Both an agency (financing) and a technical institute
⇒ Not a scientific institute : Science is done in research institutes (CNRS, CEA)
⇒ Science programs is based upon scientific proposals.
⇒ Most astrophysics instruments are developped in the institutes with CNES financial and technical support.

# 1. Astroparticles in space – A brief (non exhaustive) survey



# 1. Astroparticles in space – A brief (non exhaustive) survey



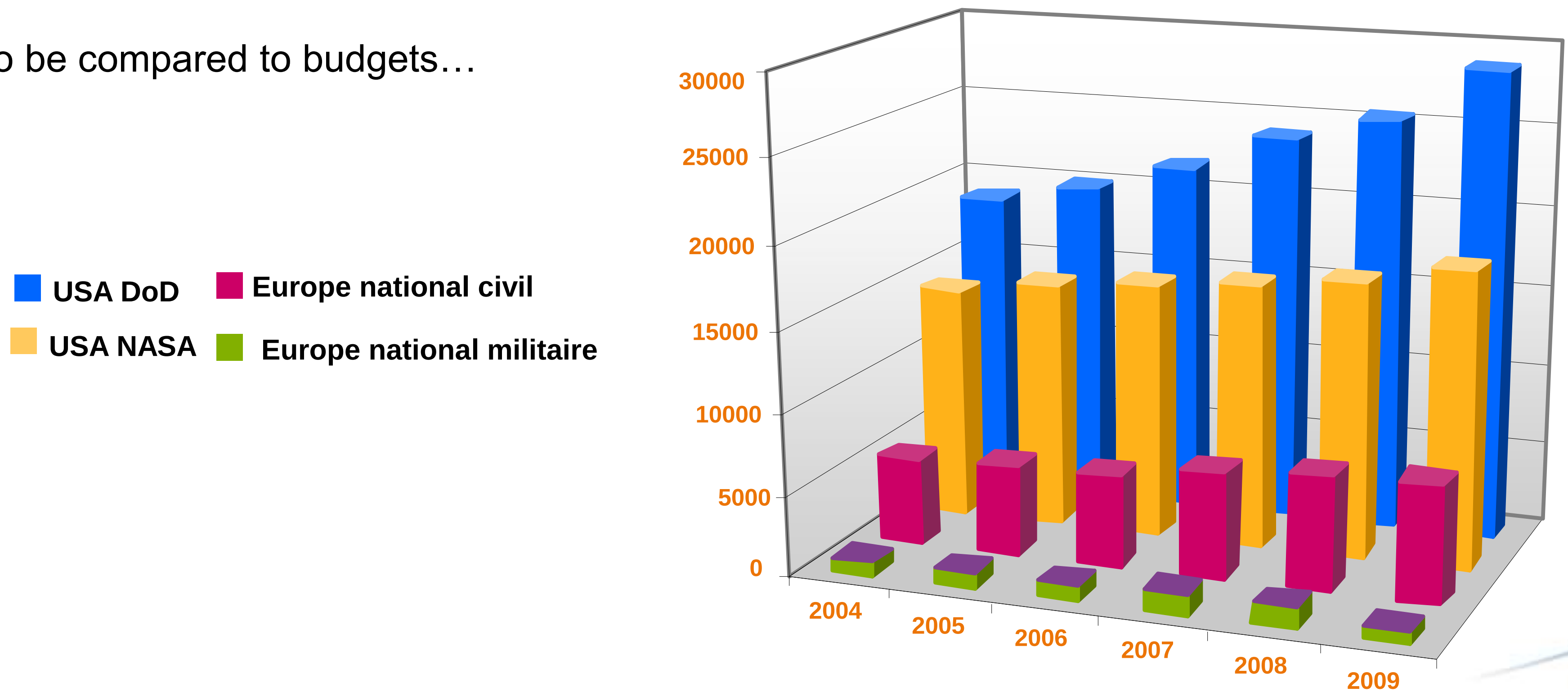
# 1. Astroparticles in space – A brief (non exhaustive) survey

## Programmatic aspects

70% “photonic” missions, from which 65% for X-rays
30% other : cosmic ray, antimatter, etc.

> 50% US-led missions
Others : Japan (particularly for X-ray), Russia, Germany, Italy, UK, France…

To be compared to budgets…

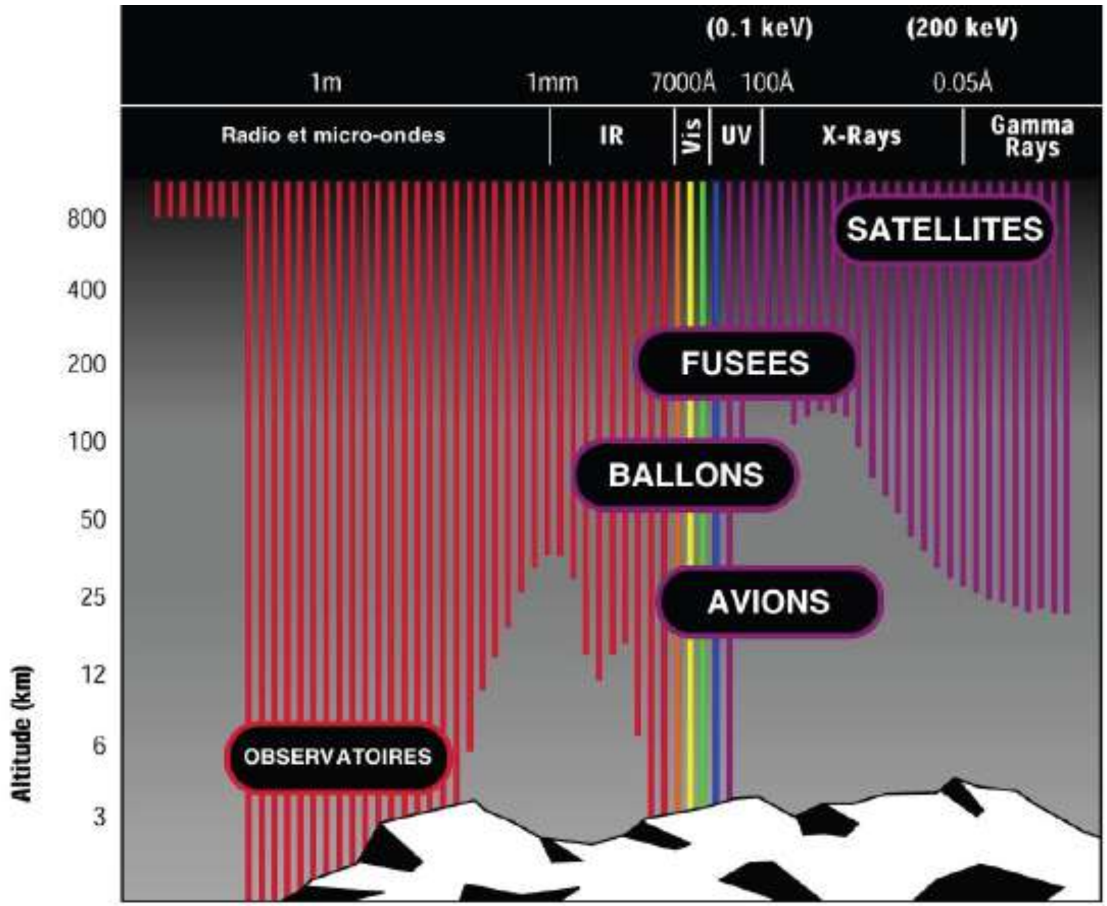


## 2. Why going to space?

### The atmosphere and the photons

The atmosphere is opaque to X-rays and gamma-rays (>0.1keV). They can only be detected from space (or stratospheric balloons).

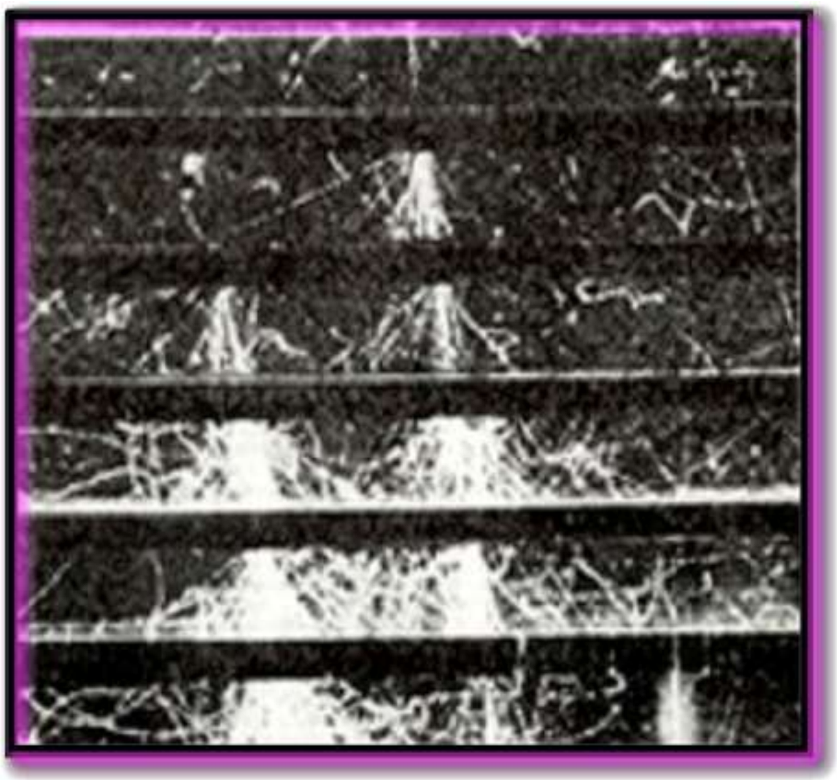
Exception : above 30 TeV gamma rays penetrating the atmopshere can be detected from the ground indirectly.

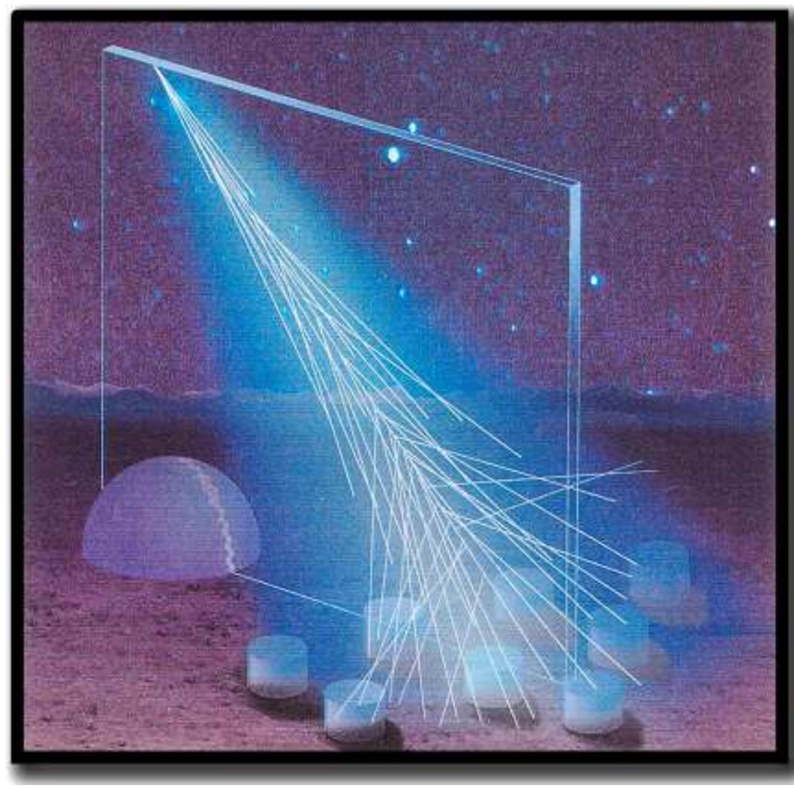


# 2. Why going to space?

## Cosmic rays detection

Relativistic charged particles (cosmic rays, CRs) are blocked by the atmosphere and therefore generally non detectable from the ground.
Exception : >100 TeV CRs are indirectly detectable from ground thanks to the Cherenkov light and the air shower of secondary particles created by their interaction with atmospheric nuclei.





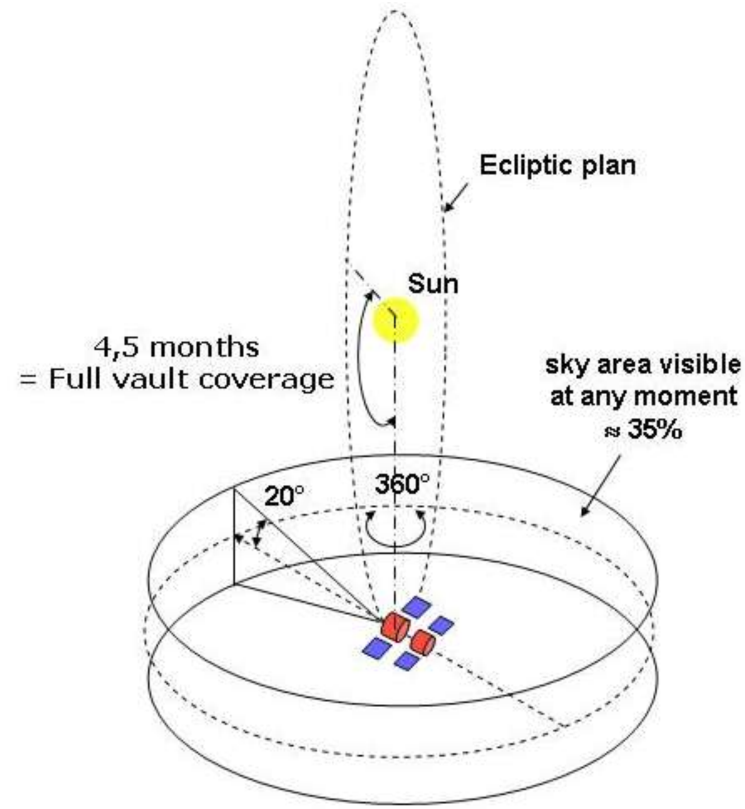
# 2. Why going to space?

## Stable mechanical environment

The only perturbators are microvibration induced by mobile elements (if any) inside the satellite (reaction wheels, coolers…). No seismic activity, no acoustic weaves, no tide in space!

## Stable thermal environment

No day/night cycles (but eclipses for some orbits).
Very stable in time (provided sun aspect angle is kept in a narrow range)
However in Low earth Orbit the Earth albedo must be taken into account




## Large accessible field of view

Large part of the sky accessible (depending on the mission)

## Long uninterrupted exposures

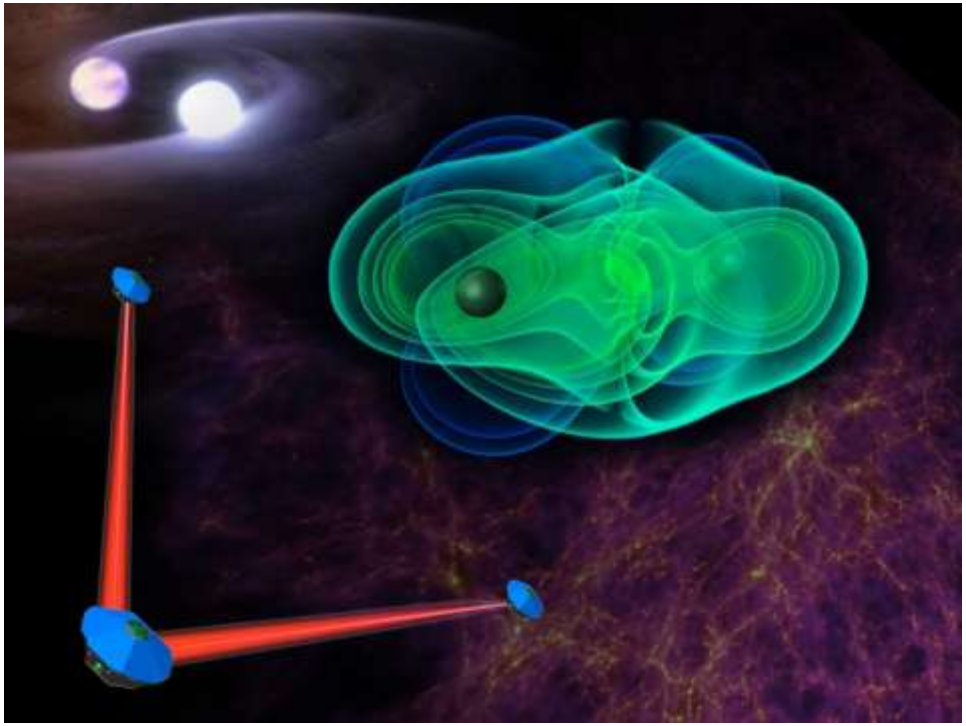
XMM, Integral : ~36h
AMS : years

## 2. Why going to space?

### Large scales for gravitationnal waves

Detection of gravitationnal waves relies on the continuous monitoring of the distance (D) between several free-falling test masses. A incoming GW will provoque a local space-time distortion, resulting in a change of this distance.

Expected changes are $\delta D/D \sim 10^{-21}$!! $\Rightarrow$ The larger D, the larger $\delta D$.
e.g. NGO : $D \sim 10^{6}$ km, accuracy $\delta D \sim 10^{-12}$m.



# 3. Constraints on a space mission

## Launcher constraints

- Mission sizing is dictated by the launcher capacity and cost

| | Ariane 5 ECA | Soyouz 2.1b | Vega |
|---|---|---|---|
| Max mass in Int[l] Space St. orbit | 21 t | 4,4 t | 2 t |
| Fairing max height | 17 m | 11,4 m | 7,88 m |
| Fairing max diameter | 5,375 m | 4,11 m | 2,6 m |
| Cost | ~170 M€ | ~80 M€ | ~45 M€ |

Ariane 5 fairing

- Mechanical design must withstand a severe environment at launch….

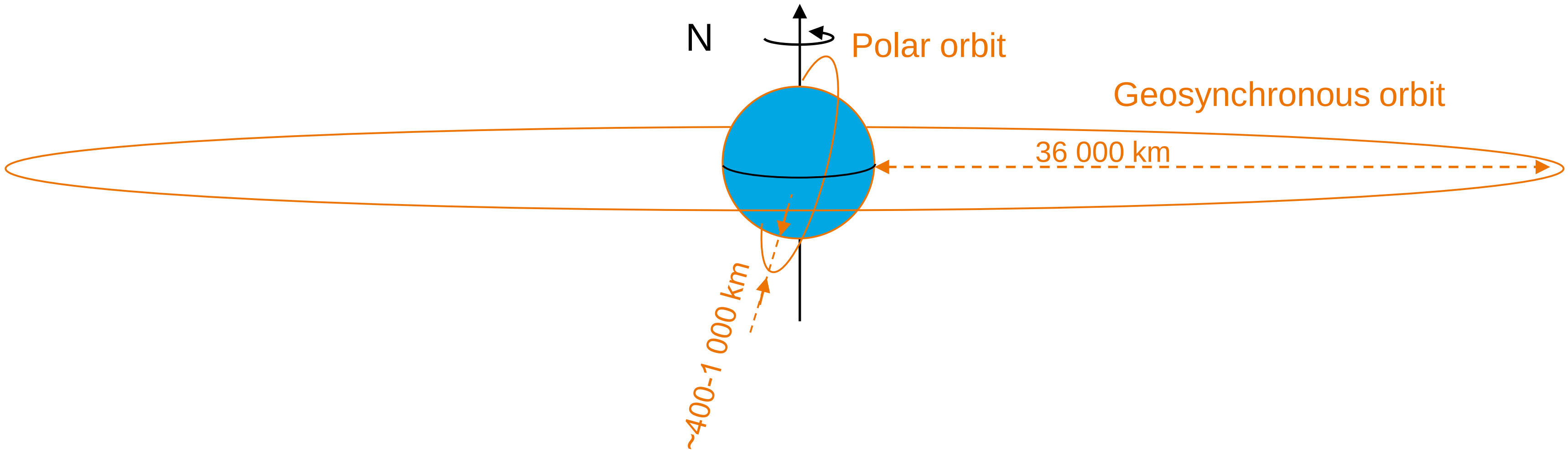
Soyouz – Ariane 5 : Static acceleration ~ 4,3g
Sinusoïdal accelerations : up to 1g for frequencies in [2,100 Hz]
Acoustic vibrations (noise) ~140 dB
Random vibrations
Shocks (Separation of rocket stages, fairing, companion satellite)

… Whereas once in orbit it will be very quiet!

# 3. Constraints on a space mission

- Constraints linked to the dominant space business (which is not science… :-\)

Launch systems are optimized for telecom (geostationnary orbit) and/or Earth observation (mostly on polar orbits) missions. Other inclination remain possible but most of time prevent from sharing the launch and therefore the cost, with another satellite, and from benefiting from existing thus cheaper platforms.




Example : most of the multimission (CNES Myriade,Thales Proteus…) low Earth orbit satellite platforms, designed for Earth observation, uses magnetocoupler taking benefit from the earth magnetic field to counteract the periodic reaction wheels desaturation (speed reduction). These magnetocouplers become inefficient for inclinations below 30°.

# 3. Constraints on a space mission

- Thermal environment
  In the vacuum, no convection for heat dissipation. Heat (from electronics mainly) must therefore be evacuated by conductive and radiative systems.
  This also induces a constraint on electronics dissipation, sometimes the development of specific low dissipation devices (ASIC…)

Spot 5 radiators

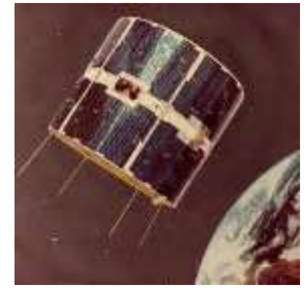
- Power constraints
  Satellites power budget is low. ~2 kW for AMS-02
  This again may impose the development of customized low consumption electronics

- Reliability and autonomy constraints
  Satellites may not be repaired. Moreover remote operations are limited. Therefore high reliability and autonomy is requested : redundancies, intensive ground testing (including ageing tests), robust onboard softwares for autonomous failures handling…

# 3. Constraints on a space mission

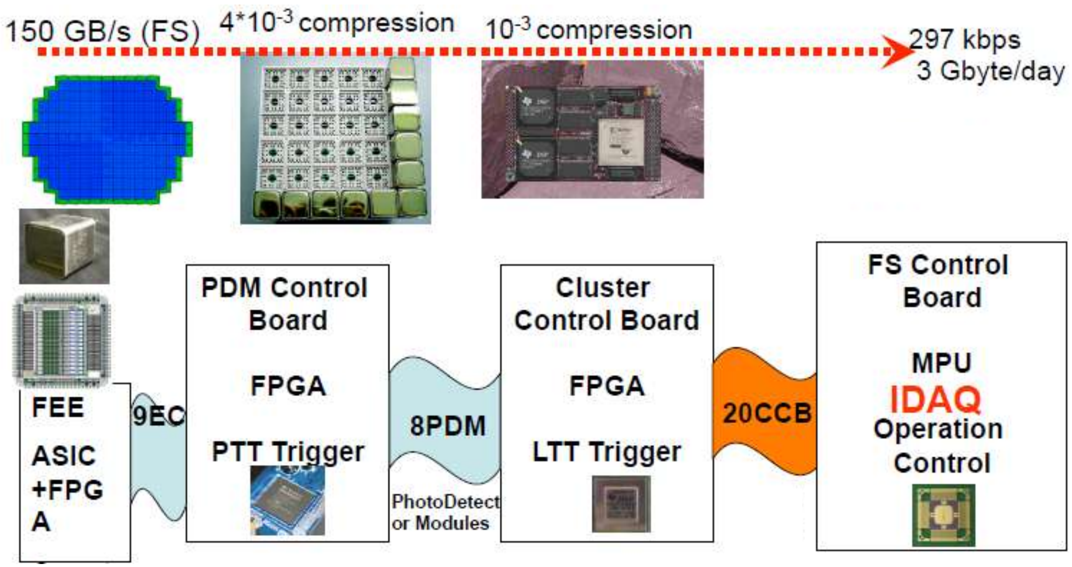
- Board/ground data transfer

More and more science instruments produce considerable volumes of data, among which a lot of « spurious » ones.
The less expensive solution would be to process all the data on ground. Unfortunately available datarates, in spite of spectacular progress, do not allow that.
Thus onboard filtering, compression and storage functions must be implemented.



COS-B (1975) : 0.3 kb/s ~3 Mb/day

FERMI (2008) : 40 MB/s 160 Gb/day



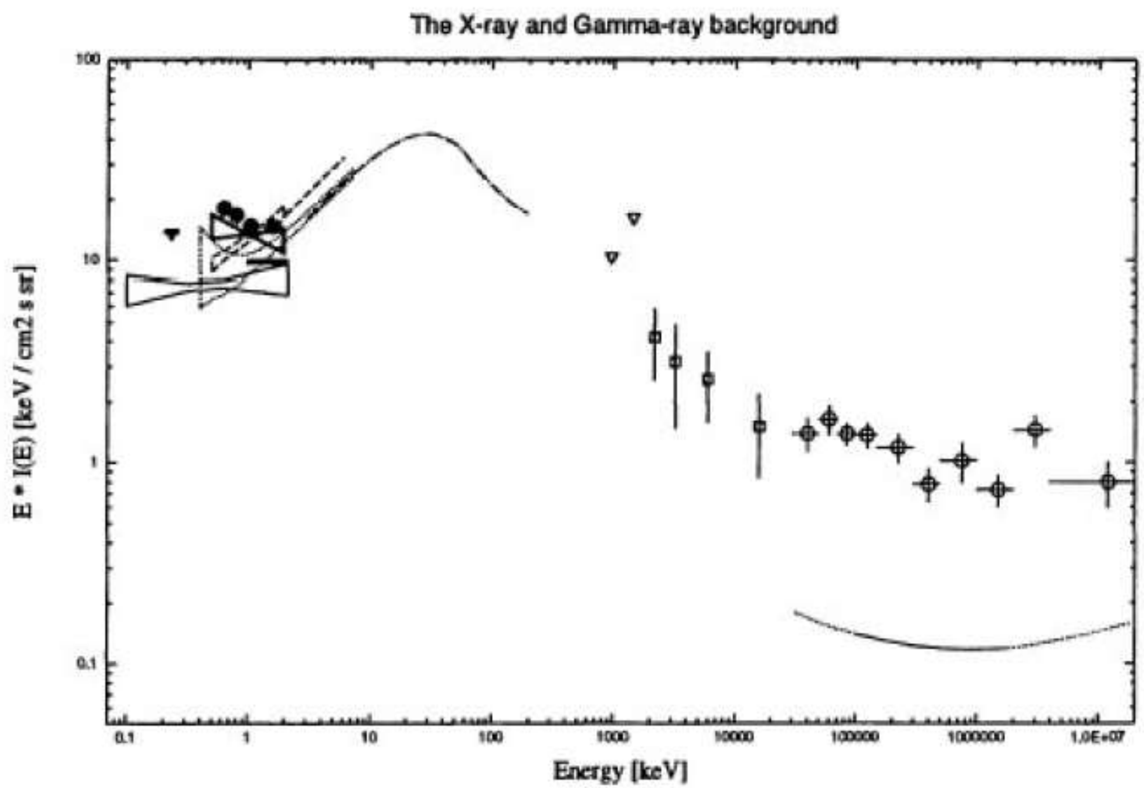

The JEM-Euso Data reduction block scheme – courtesy JEM-Euso collaboration

# 3. Constraints on a space mission

• Environment : Cosmic diffuse background

Space is permeated by a diffuse X and gamma diffuse emission mainly due to superposition of the emission of active galactic nuclei (AGNs) at different redshifts.

This emission is the major part of the background in X-rays (E<50 keV) X and gamma detectors must be protected fromit by collimators blocking the photons coming from outside the intrument field of view.




From Hasinger, 1996, A&ASS, 120, 607.

# 3. Constraints on a space mission

- Environment : Charged particles

Charged particles are essentially :
- Protons and electrons from the solar wind
- Cosmic rays : Relatisvistic atom nuclei (mainly H and He) and electrons
- Most solar particles and the less energetic cosmic rays are trapped by the Earth magnetic field in radiation belts.

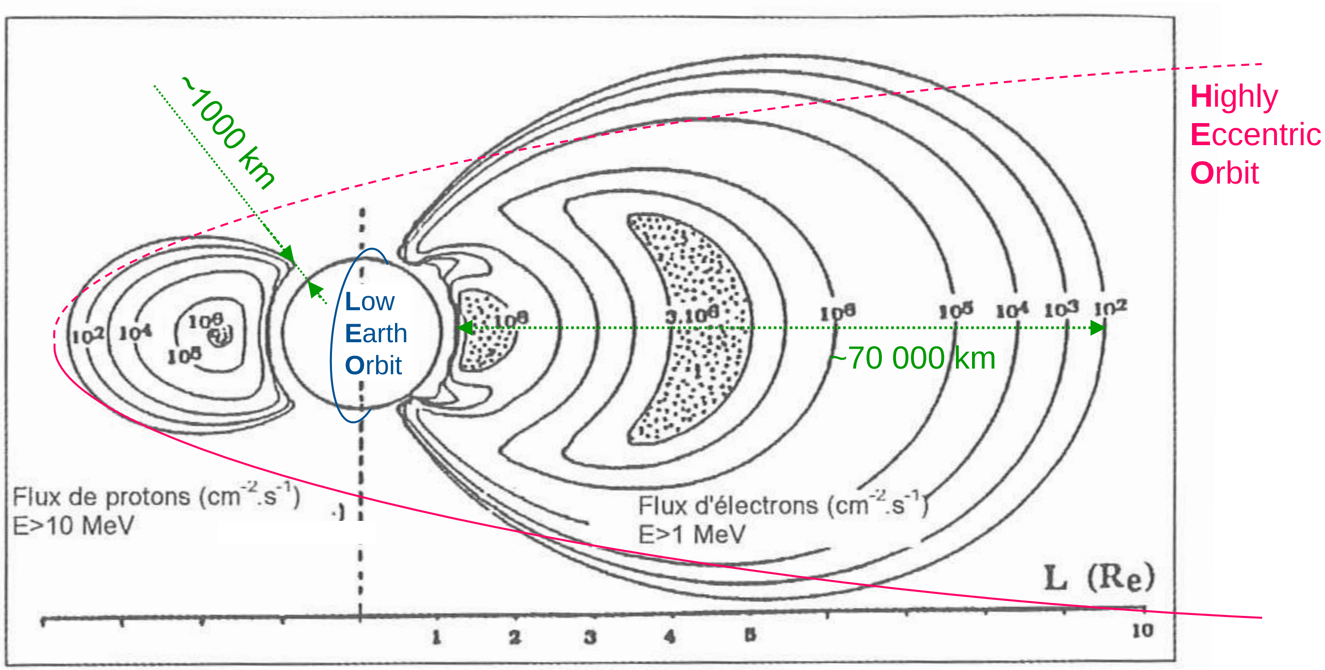
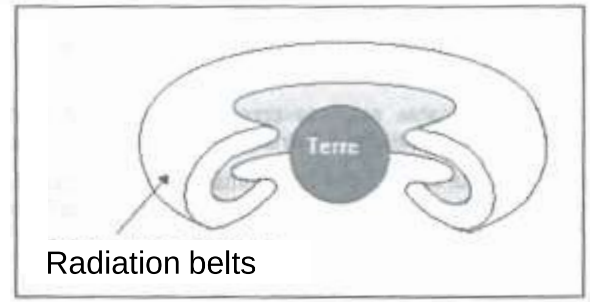
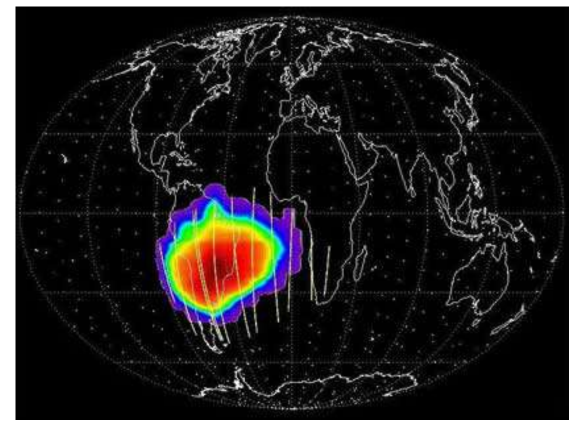



Figure IV.77

Cartographie des flux dans les ceintures de radiations



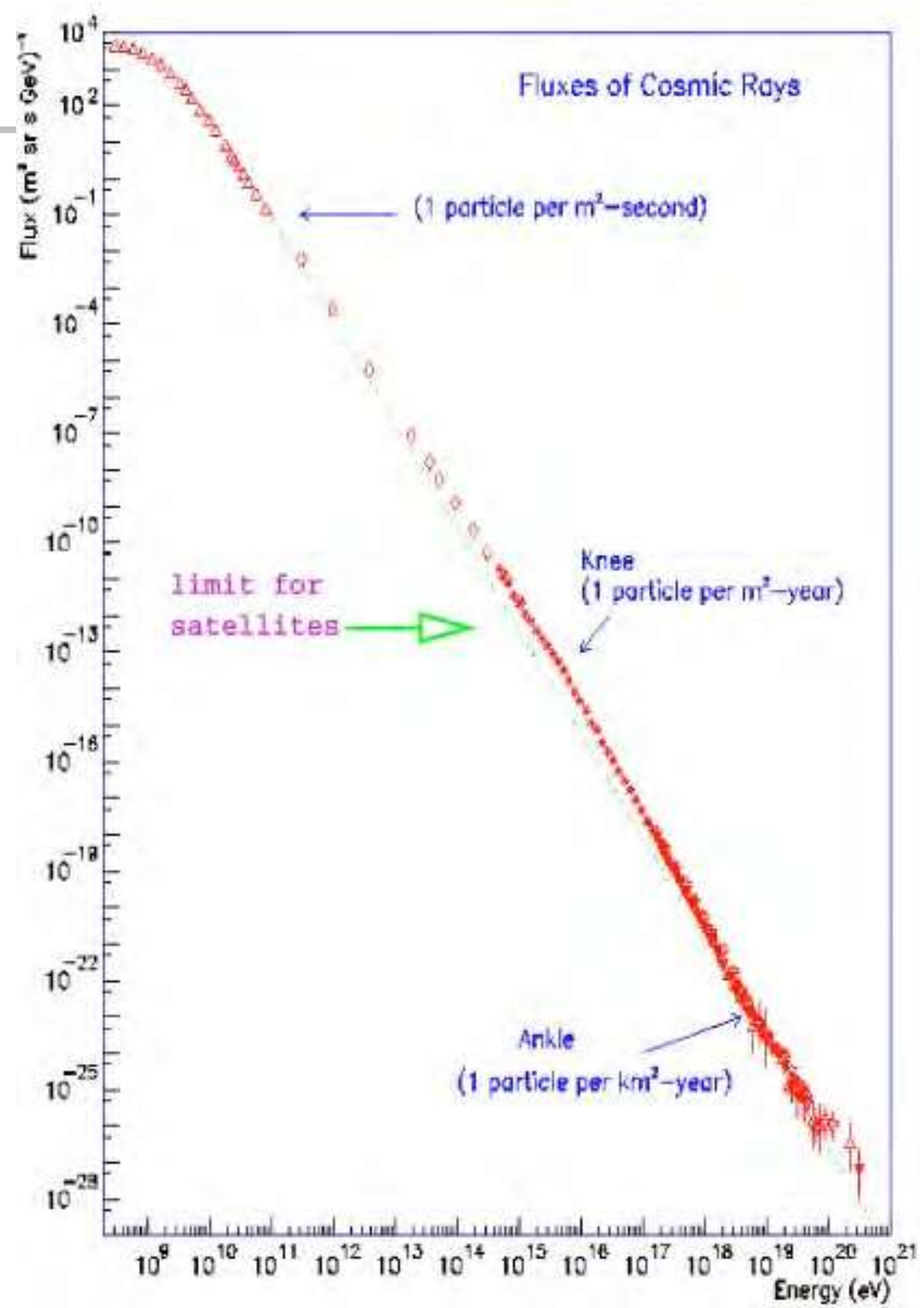



South Atlantic Anomalie (SAA) :
Protons belt lower (<600 km) than elswhere
(⇔ Bias between magnetic and geometric centres of the Earth)
Crossed seval times a day in LEO

# 3. Constraints on a space mission

- Environment : Charged particles

Charged particles are essentially :
- Protons 90%
- $_4$He nuclei 9%
- Electrons, antimatter 1%



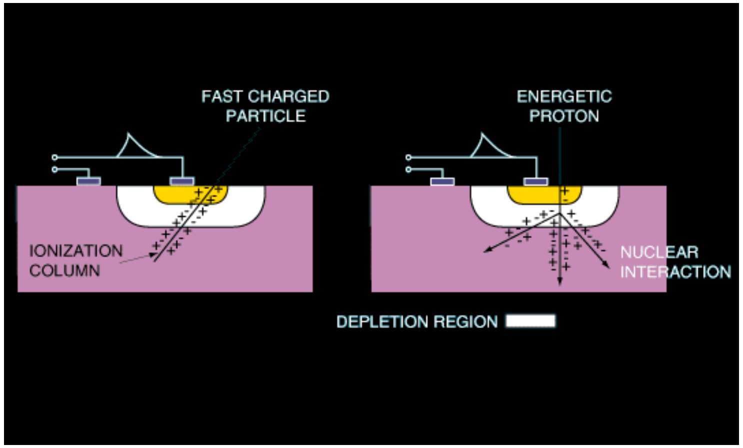
# 3. Constraints on a space mission

- Protons and ions may trigger the detection system by direct interaction in the detectors.
  They also may activate the materials of the satellite by spallation reactions, producing gamma photons either immediately or later.
  Theses processes create **noise** in the measure, which dominates the cosmic diffuse background at high energy (E>500 keV).

⇒To be taken into account for the design of the satellite : minimization of the mass in the vicinity of the detectors for X-ray mission, choice of the materials…
NB : unfortunately this somehow is contradicted by the need for shielding from the cosmic background!

# 3. Constraints on a space mission

- Protons and cosmic rays may provoque Single Event Effects (**SEE**) in microelectronic device :
  - Single Event Upset (SEU) are change of state of a device (e.g. change of a bit in a memory). They are not destructive in general but onboard software must be robust to SEUs.
  - Single Event Latchup (SEL, ~short-circuit), Single Event Gate Rupture (SEGR) and Signe Event Burn-out (SEB) are destructive events.

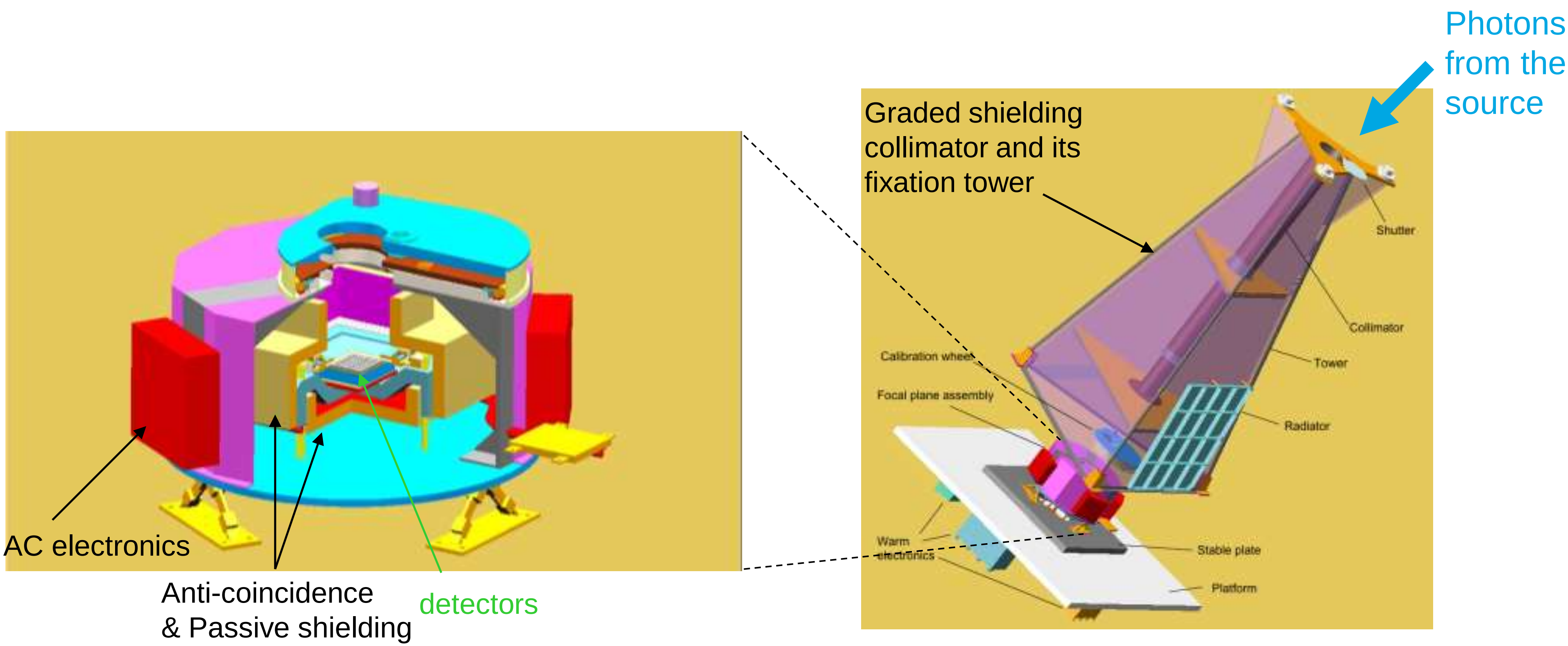



- Electrons may create a local electrostatic charge and then an ElectroStatic Discharge (**ESD**) event, that may induces dangerous power voltage transients.

⇒ Components must be “space qualified” : Specific design and tests
⇒ Shielding is often added (e.g. 1cm Aluminium)
⇒ Redundancy is quasi systematic (except for microsatellite)
⇒ Satellite grounding

# 3. Constraints on a space mission

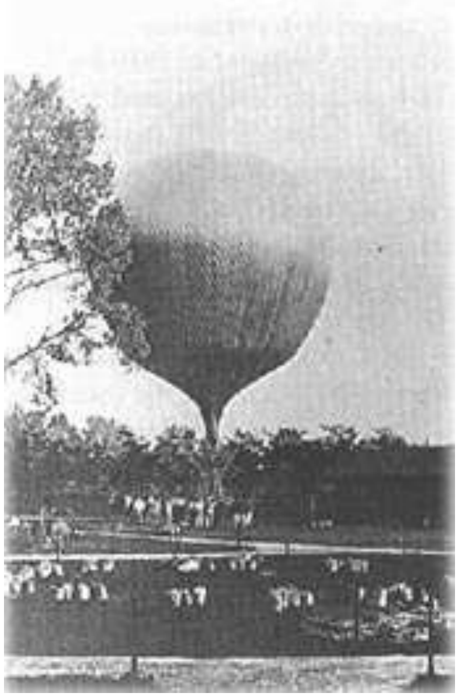
Example : Simbol-X protection for background

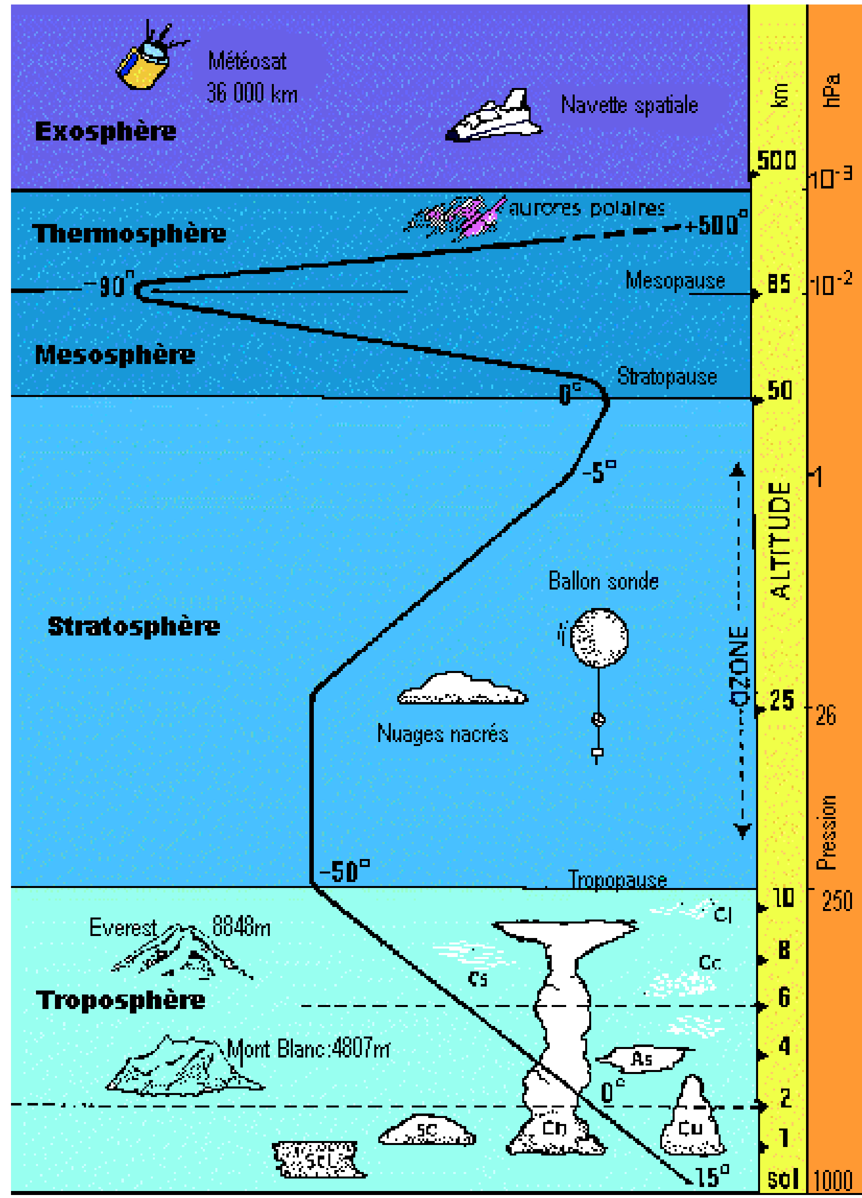



~ 60 kg and 20 W from an overall 135 kg & 110 W instrument budget

# 3. Stratospheric balloons

Balloon experiments where the ancestors of « space science » : First detection of Cosmic rays by V. Hess, 1912



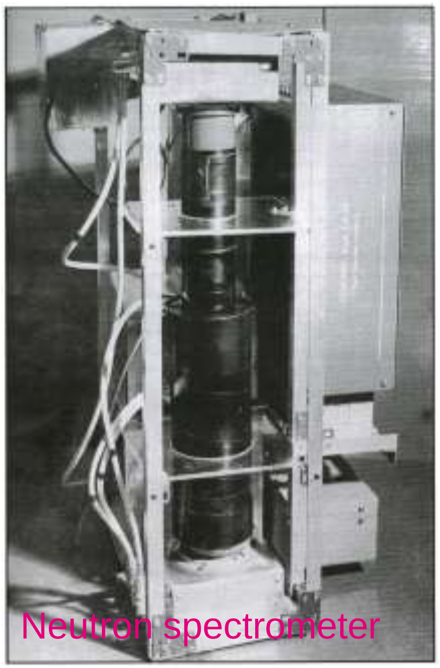


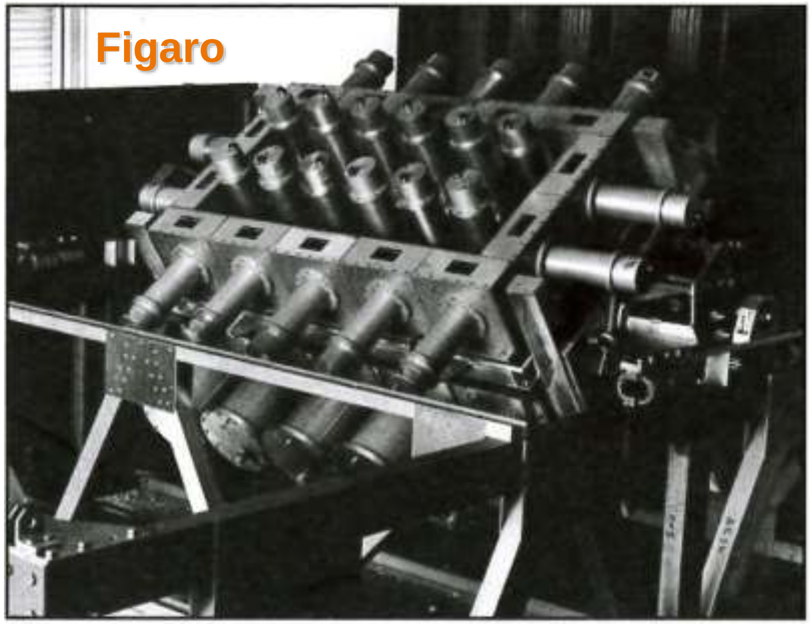
COUPE DE L'ATMOSPHERE

Widely used since the 19th century for atmospheric studies, and since the 60's also for astronomy

# 3. Stratospheric balloons

The 60's : Decade of astroparticles pionneers
Numerous experiments in US, URSS, France…
=> Solar physics, particles trapped in the Earth magnetosphere, X and gamma background, first pulsars, cosmic electrons,  …



# 3. Stratospheric balloons

Pros :

Flights out of the dense layers of the atmosphere (a few hPa) => Access to all wavelengths + cosmic rays
Relaxed mass and size constraints (up to a few tons, up to 10 m)
Low cost (a few M€)
Short development (~2-6 years)
Few constraints (launch when ready, re-usable, refurbishable, +/-repairable)
Demonstration of future space concepts and technologies
Educational role

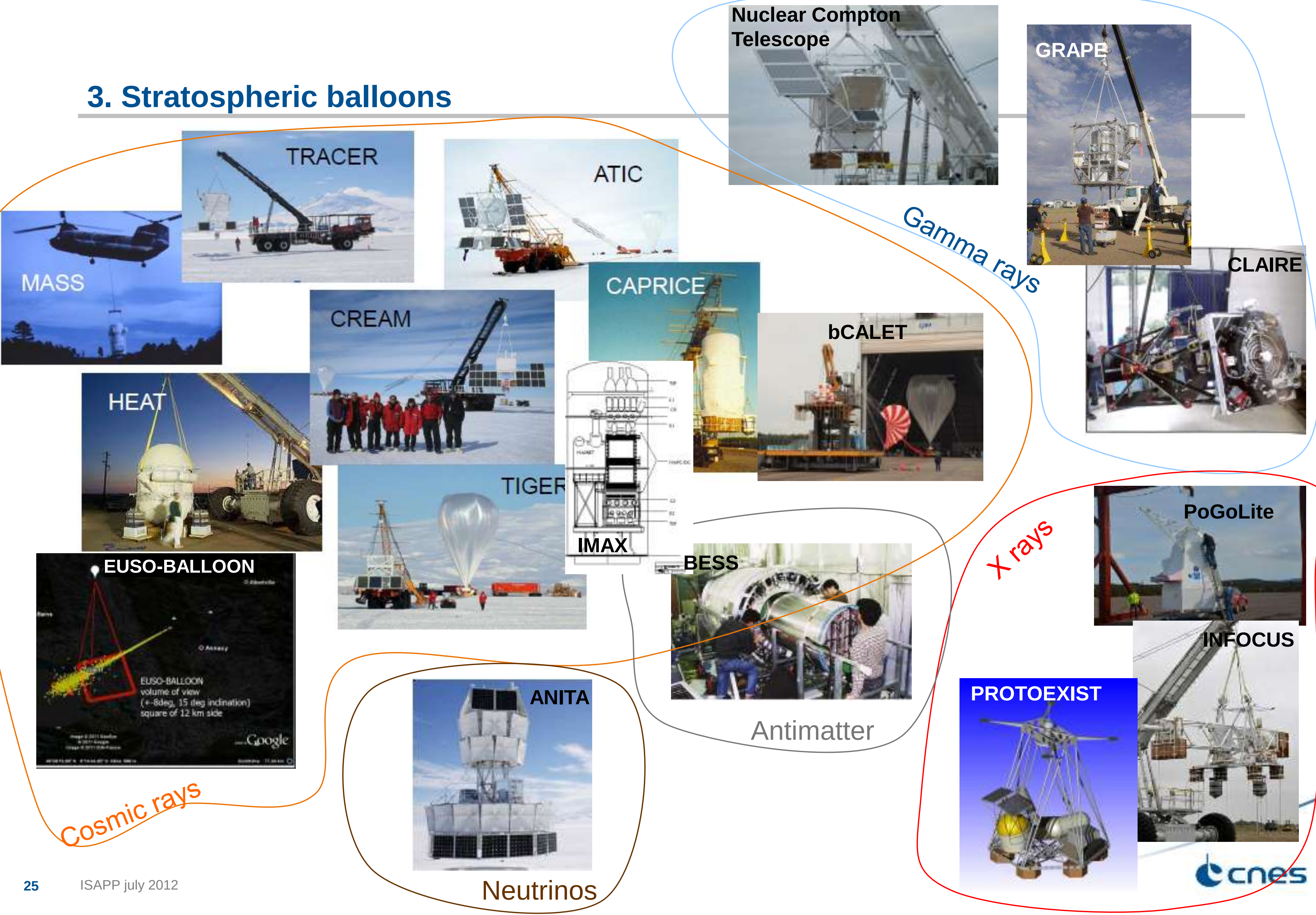
| Type de ballon | Ballons stratosphériques ouverts (BSO) | Montgolfière Infrarouge (MIR) | Ballons Pressurisés Stratosphériques (BPS) |
|---|---|---|---|
| Altitude de vol | de 15 à 40 km | 30 km (le jour) 20 km (la nuit) | 18 à 30 km (le jour) |
| Volume de l'enveloppe | de 3000 à 1200 000 m3 | 45 000 m3 | 900 m3 |
| Masse emportée | plusieurs tonnes | 60 kg | jusqu'à 60 kg |
| Durée du plafond | de 7 à 12 h | plusieurs semaines | quelques mois |
| Gaz porteur | hélium | air chaud (hélium pour le décollage) | hélium ou hydrogène |

Cons :

Residual sky background (for UV, VIS, IR)
Particles environment (interactions cosmic rays/atmosphere)
Limited flight duration (max ~1 month)
Meteorological aleas
Risks

Nuclear Compton Telescope – 200 keV – 10 MeV

# 3. Stratospheric balloons



# Conclusion

**Space widely used since the 60's in the study of astroparticles**

**Why going to space? Only when not possible from ground**
Space = costly (lauchers, reliability) and development are long (up to 10 years or more)

AMS-02 : ~1.5 G$
XMM-Newton : ~1 G$
Fermi : ~690 M$
Integral : ~500 M$

Space experiments must be "thought" spatial from the very beginning
Reuse of ground concepts or components is limited (Phobos-Grunt!)

Ground and space experiments are complementary
Combined exploitation of different experiments is rich! (HESS+Integral+Fermi)

Balloons offer a good scientific return for a limited investment.
However mind the ceomplexity of the payload and the stratospheric particles environment

# Session 2

**Elements of design of a space mission**

**Cycle of development of a space project**

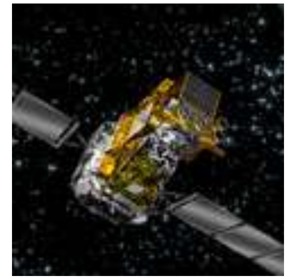
**Notions of programmatics**

**Astroparticles in space : perspectives**

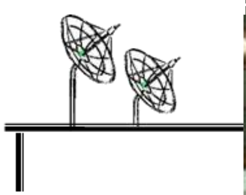
# Elements of design of a space mission

The general scheme of space system is :

- A space segment : the satellite(s)
- A ground segment including :
  - A Mission Operation Center
  - A Science Operation Center
  - Ground antenna(s)
- A launch system, including :
  - The launcher
  - An operation center
  - Ground antennas
- In addition, for science missions, science teams check the instrument behaviour and performances, and analyses anomalies.



Users




Launcher operation center

Mission Operation Center (MOC)

Science Operation Center (SOC)

# Elements of design of a space mission

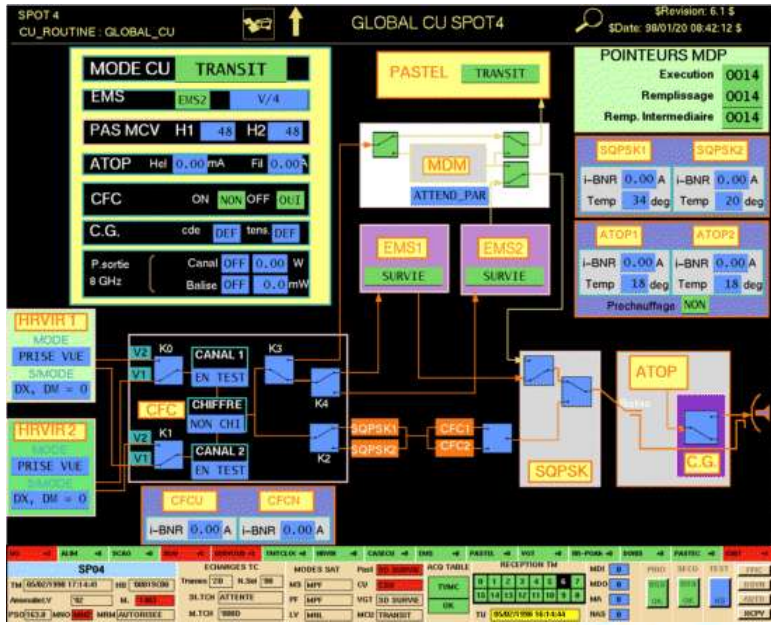
- The MOC :
  - plans the operations
  - prepares and uploads (via the antennas) the telecommand (TC) plans
  - receives the satellite raw telemetry (TM), both the scientific one and the housekeeping one (general monitoring of the satellite)
  - realizes the first level TM processing : L0 (« decommutation »)
  - monitors the satellite's health and orbit
  - sends to the SOC the scientific TM and auxiliary data (orbit parameters, satellite pointing, satellite clock…)
  - sends information for science planning to the SOC (orbit prediction, satellite maintenance operations…)

⇒ The « close contact » with the satellite

⇒ The MOC includes technical tools (computers, softwares, satellite simulator, screens…) and human ressources (technicians and engineers)

⇒ In routine phase it is operated most often in opening hours, with « on call » duty during nights and week-ends in case of anomaly

⇒ During launch and commissionning, or in exceptionnal situations (anomaly recovery, …) « H24 » operations may be needed




MOCs are multimission for budgetary reasons.

# Elements of design of a space mission



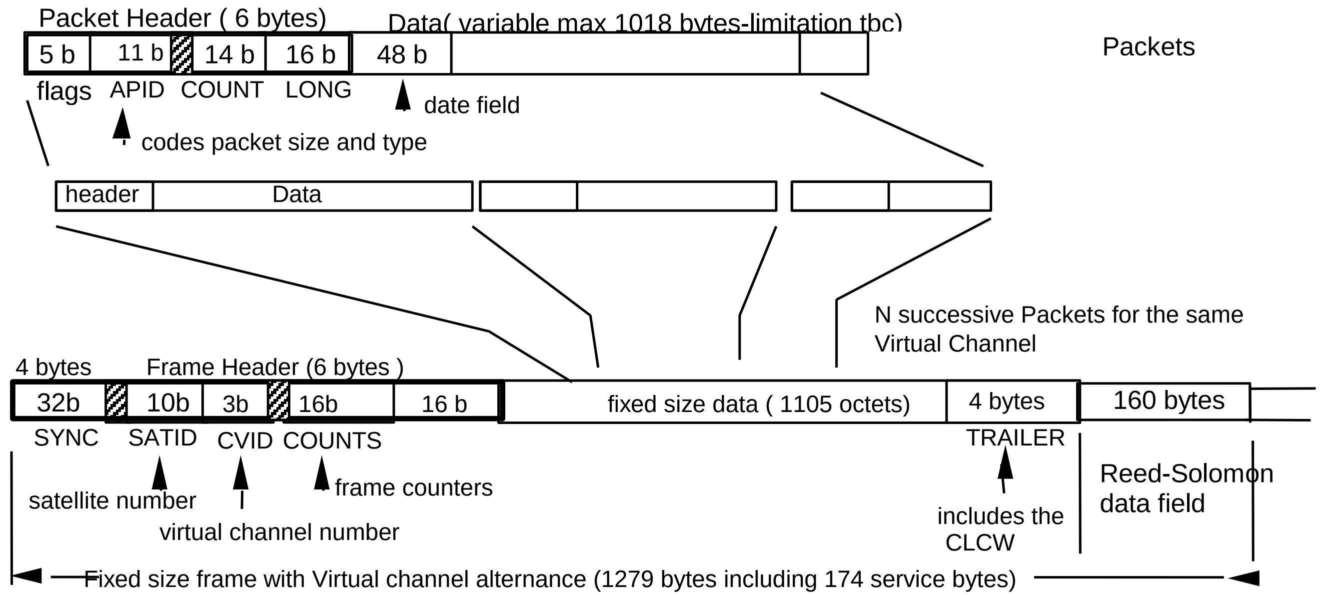
## Elements of design of a space mission

The SOC :

- distributes the observation time (through regular AOs) (for observatories)
- plans the observations and the calibrations, and transmits them to the MOC
- produces the L1, L2 (sometimes L3) products (see next slide)
- distributes the products to the community
- update the instruments transfer function
- archive the data
- ensures users' support

# Elements of design of a space mission

« L0, L1, L2, L3 »???
⇒ Standard definition of different levels of science data processing.




**Routing the TM packets accross the CCSDS layers**

Synchronisation marker: 1ACFFC1D (hexadecimal value)

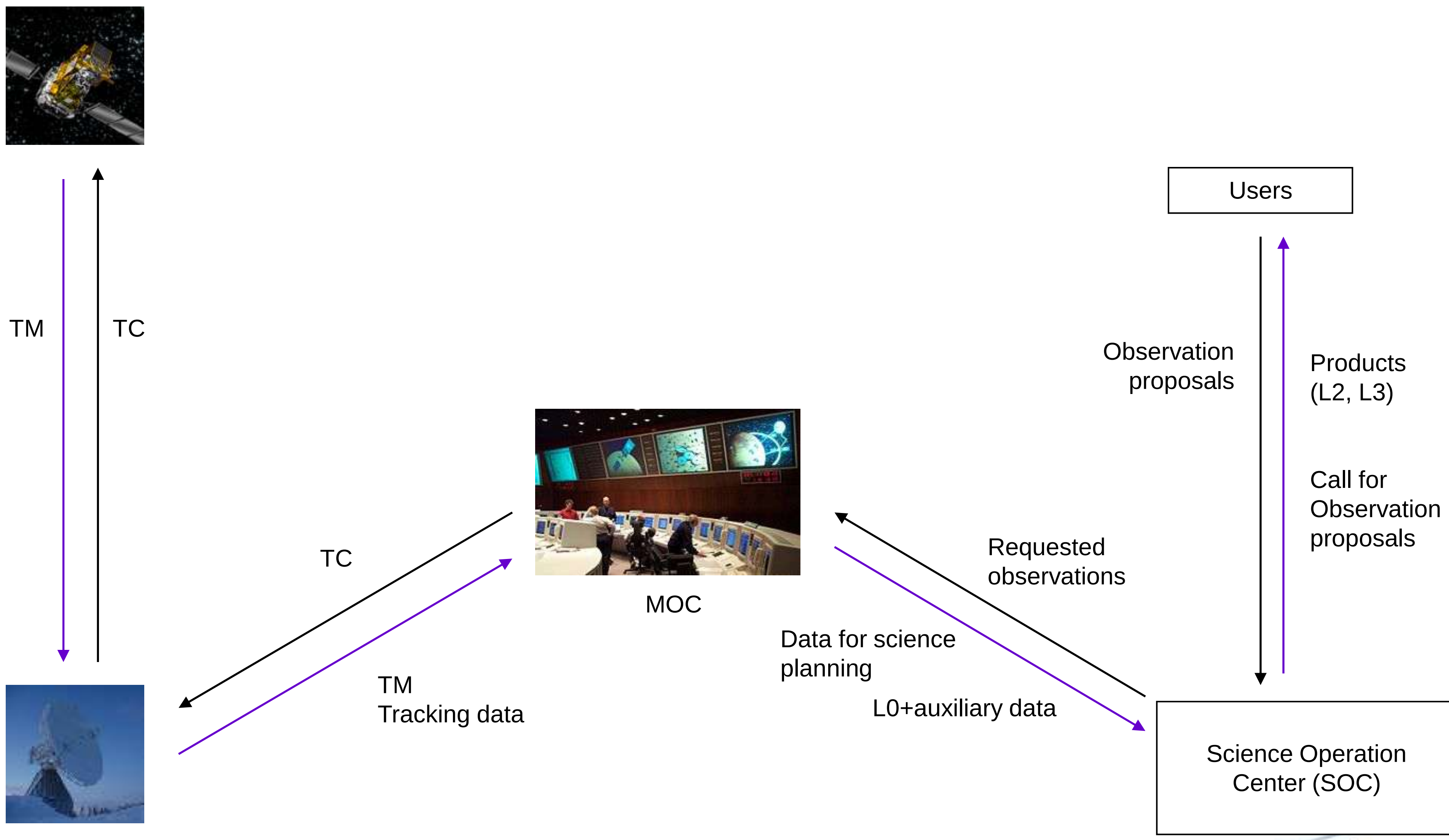
other fields

L0 : Decommuted TM from satellite. Instrument output data are split and coded to fit into standard TM format, and additionnal bits are added (synchro bit, correction codes…). L0 data correspond to the decoded information, i.e. equivalent to the output of the instruments, converted in decimal system.

L1 : TM converted into physical values : flux, charge collected in a pixel,…. This requires calibration tables.

L2 : Data satellite-independent, i.e corrected for jitter, temperature variations, detector response… Corresponds to the targeted scientific data : maps, spectra, light-curves…

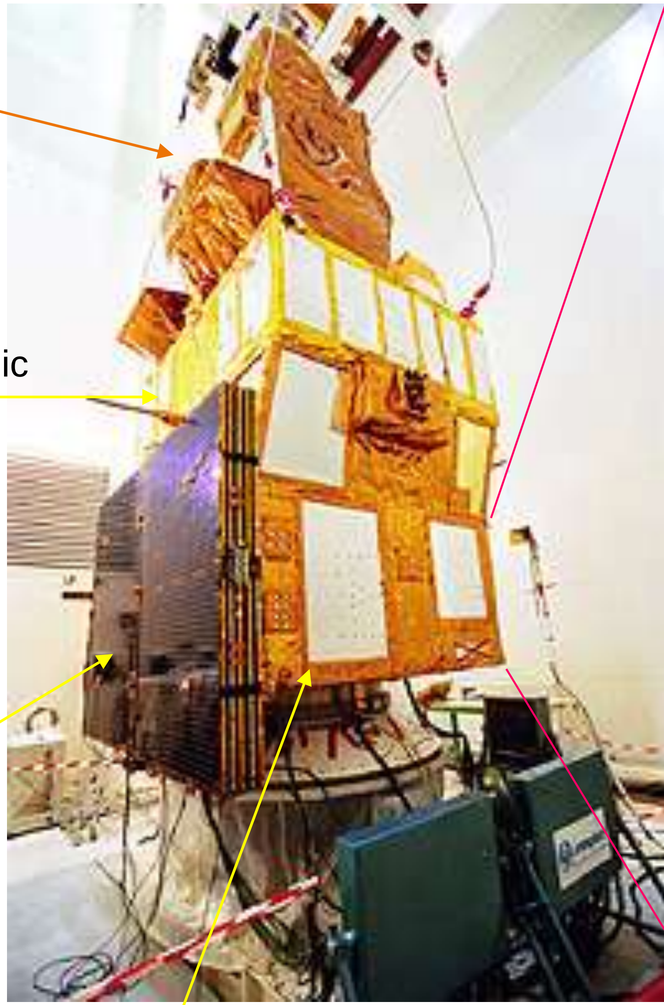
# Elements of design of a space mission



# Elements of design of a space mission

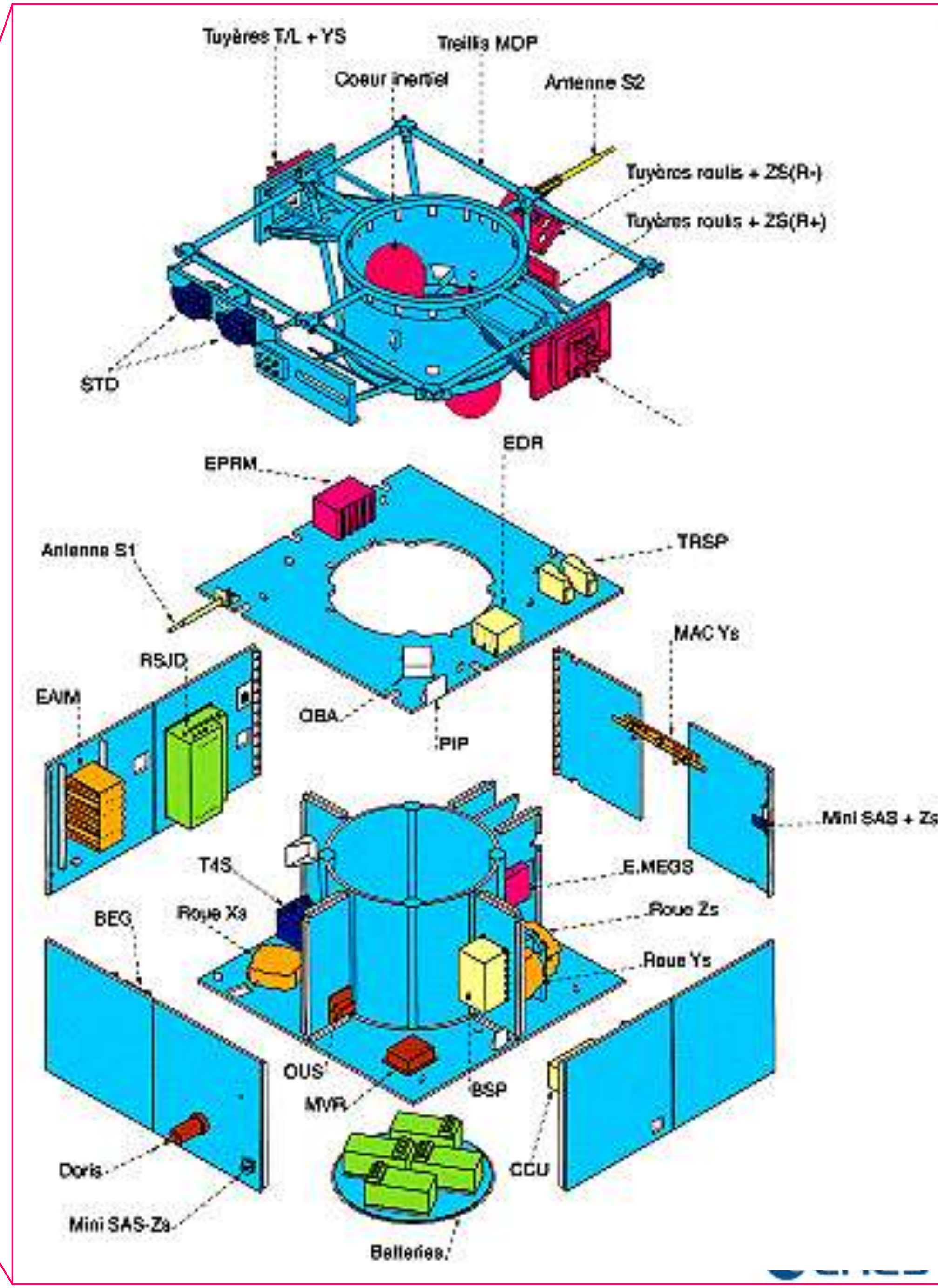
Instruments

Payload electronic bay



Solar panels

Service module



# Elements of design of a space mission

Main functions of the service module :

• Power supply : production, regulation, distribution…

• Attitude determination and control system (ADCS)

• Propulsion subsystem : orbit corrections

• Structure : to ensure a stable interface with payload, to withstand launch, to damp partially the vibrations towards the payload.

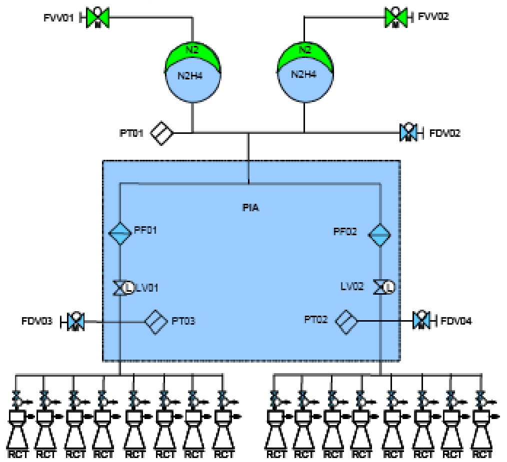
Typical technical solutions :

Solar panels, battery, switches,…

Determination : Stars'sensors
+ gyroscops during manœuvres
+ navigation&command softwares
Control : Reaction wheels
(thrusters in safe mode)

Pressurized tanks + Pipes + Valves + Pressure regulators + thrusters (typically a few N each) – Propellant : hydrazin $N_2H_4$

Honeycomb, aluminium, carbone fiber… depending on the required thermo-elasticity stability




# Elements of design of a space mission

## Main functions of the service module :

• Thermal control : due to the absence of convection, some parts need to be cooled down and some heated in order to keep equipments in the nominal range temperature

• Satellite management

• Telemetry, Telecommand & Tracking

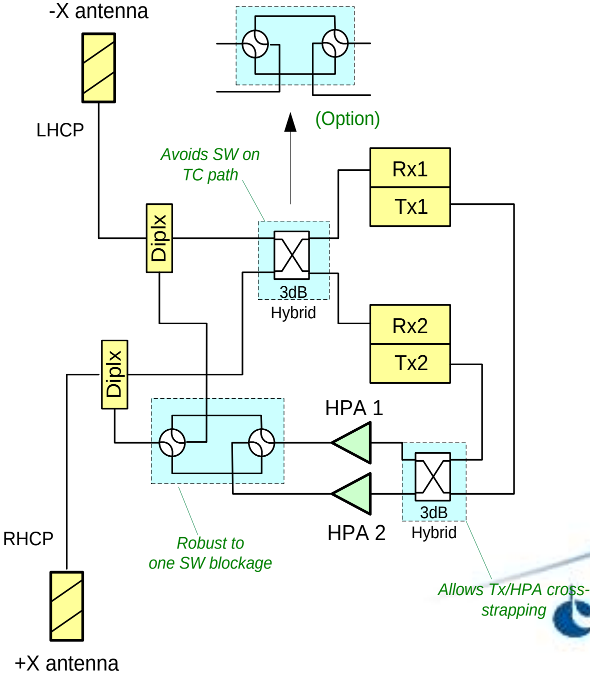
• In addition, specific functions may be required by some scientific missions. E.g. Drag compensation system with microthrusters on Microscope and LISA Pathfinder

## Typical technical solutions :

Heaters ; thermal links (Cu…); Pipelines; radiators

Onboard computer + software + communication network

Emitter, diplexers, …antenna(s)



# Elements of design of a space mission

## A particular case : formation flying satellites

In 2008 CNES and ASI achieved a phase A on the hard X-ray Simbol-X mission, using two spacecrafts in formation flight to increase the focal length and therefore the high energy thresholds. The concept was deemed feasible but the project was abandonned for budgetary reasons.
SX

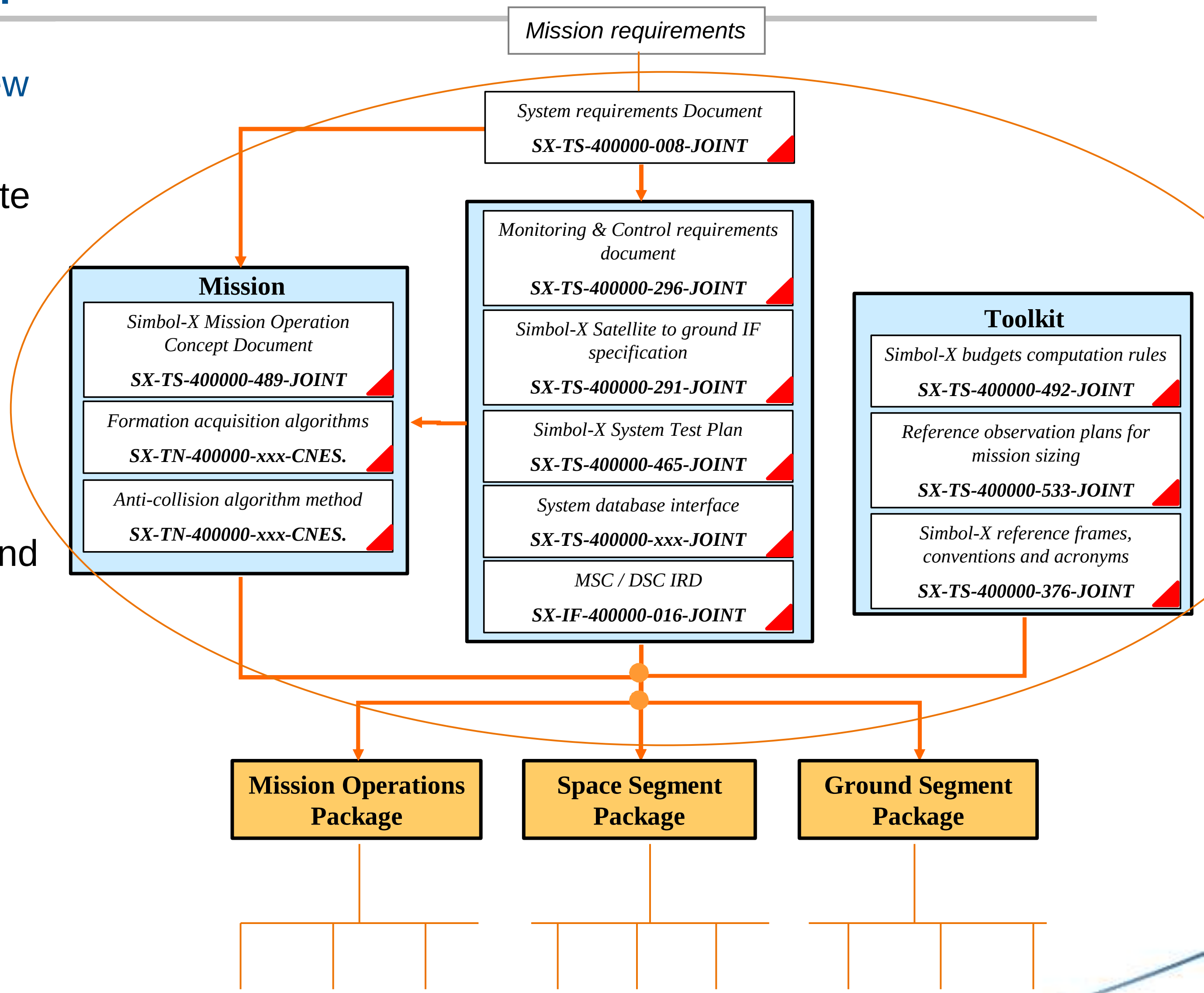
In 2010 the Swedish PRISMA technological mission demonstrated for the first time various formation flight configuration in space.
http://www.youtube.com/watch?feature=player_detailpage&v=SAkf9qISRhY

# Elements of design of a space mission

## Importance of a « system » view

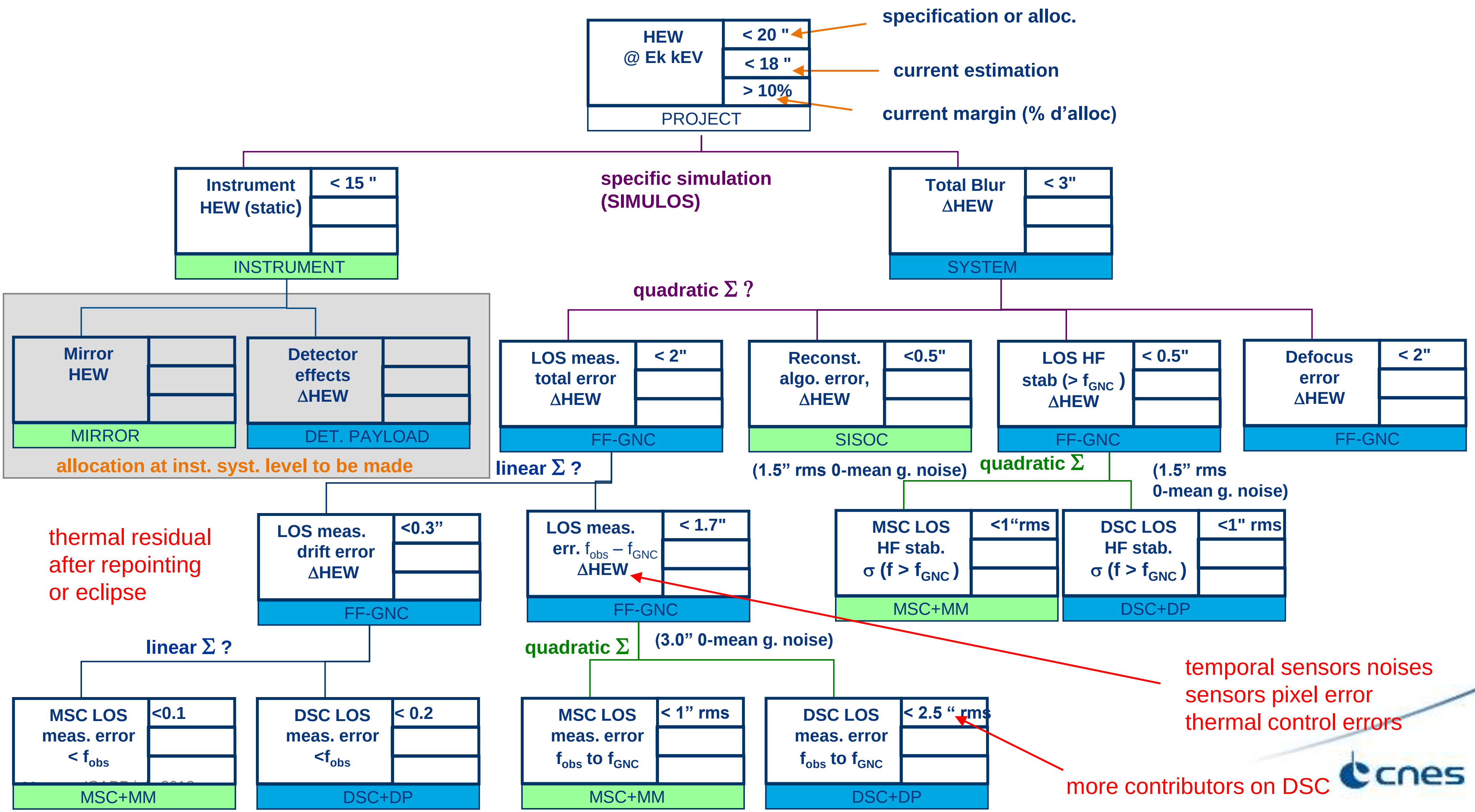
A mission, a satellite, a ground segment, an instrument are note just « boxes » put together.
They are systems.

In practical this translates by a system level layer, responsible for the declination of mission requirements to the different subsystems (« flow-down »), and for their validation.



# Elements of design of a space mission

## Importance of « system » : Simbol-X allocations for the angular resolution requirement

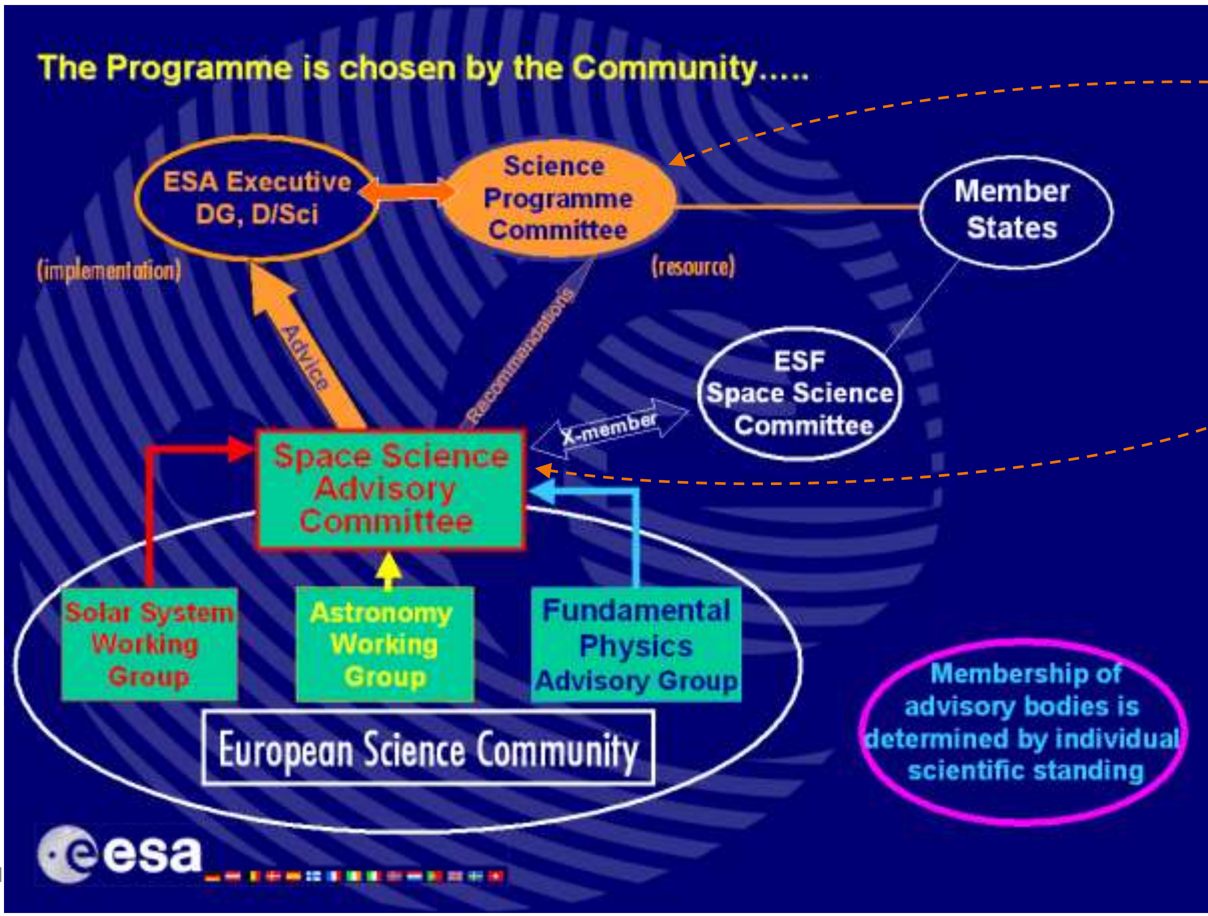


# Cycle of development of a space project

Space projects are managed by space agencies.

Scientific space ideas or projects are submitted to agencies (regular calls), then evaluated by them : science interest, feasibility, cost, risks,…

Evaluation involves peer reviewing by scientific consultative committees, appointed by agencies

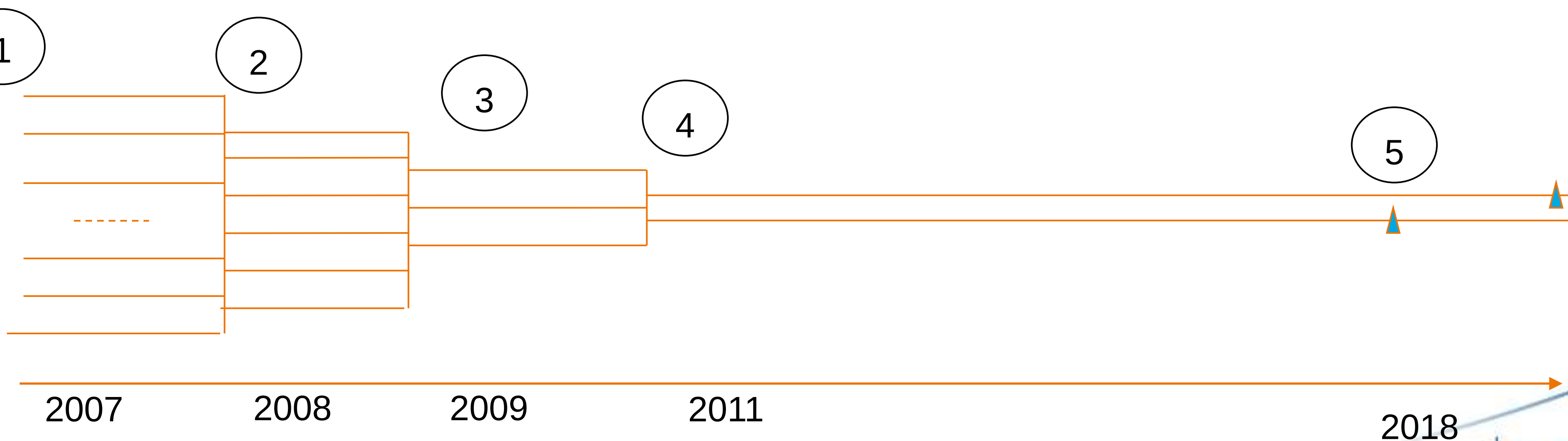



e.g. 3 May 2012 : SPC selects JUICE as the next ESA large mission, upon SSAC recommandation

## Cycle of development of a space project

The selection process : the case of the ESA Cosmic Vision M1&M2 (medium) missions

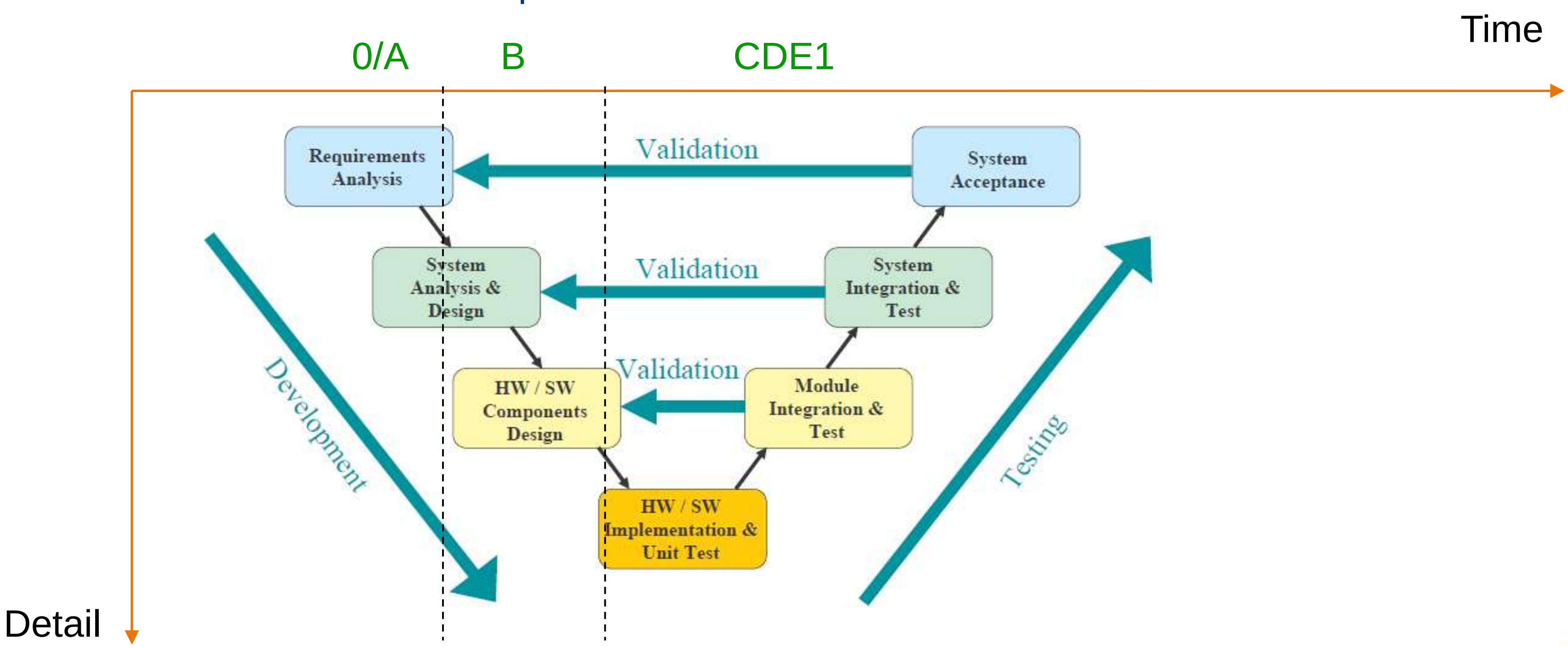
1. Scientific teams propose space missions to agencies
2. Scientific proposals are pre-selected by agencies for feasibility studies (phase 0)
3. Missions are again down-selected for definition studies (phase A/B1, or A/B1)
4. 1 (or more) mission is selected for implementation (phase B2CDE1)
5. Launch



# Cycle of development of a space project

## Life of a space project

| | |
|---|---|
| **Phase 0 / A** | Mission analysis / feasibility |
| **Phase B** | Preliminary definition |
| **Phase C / D** | Detailed definition / Production - Qualification |
| **Phase E1** | Launch campaign and in orbit validation |
| **Phase E2** | Exploitation |
| **Phase F** | End of life operations |



# Cycle of development of a space project

## Validation : the « Model philosophy »

Whenever possible, requirements are verified by the most simple way : computation, simulations…
However, this not always possible and « hardware-in-the-loop » tests are necessary.
If we wait for the real satellite to perform validation tests, we will have to dismantle it as soon as a non compliance imposes a modification…. and manipulations of the satellite are very delicate!

Producing different models allows to start the validation very early (phase C), with possible modifications before production of most subsystems. Models are produced for the different subsystems.

Space projects includes at least the following physical models :
- Structural Models (SM) : Representative of structure (shape, materials); equipments are represented by dummies, realistic for mass, stiffness, inerties. Once « vibrated », it validates the structural design, and defines the requirements for the equipments it will host.
NB : the SM is sometimes replaced by a Structural and Thermal Model (STM). Same as SM but also realistic for thermal behaviour (Insulation, heaters to simulate dissipating electronics…). It is tested in a vacuum chamber, with spots mimiquing the Sun, to validate the thermal design.

-Engineering Models (EM) : Real representative equipment and wiring. Functional validation, interfaces validation, integration procedures validation, electromagnetic compatibilities verification…

- A Qualification Model (QM) : similar to the FM. Undergoes exhaustive environment (vibration, thermal…) testing with levels higher than required

- A Flight Model (FM).

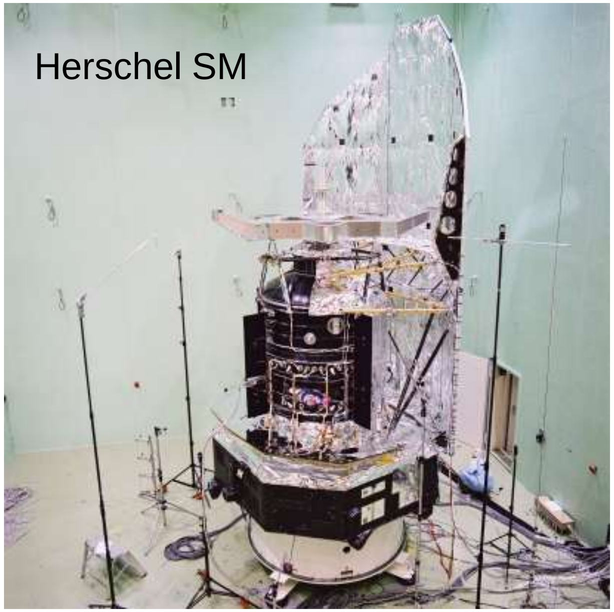
- A Spare (optionnal) : identical to the FM

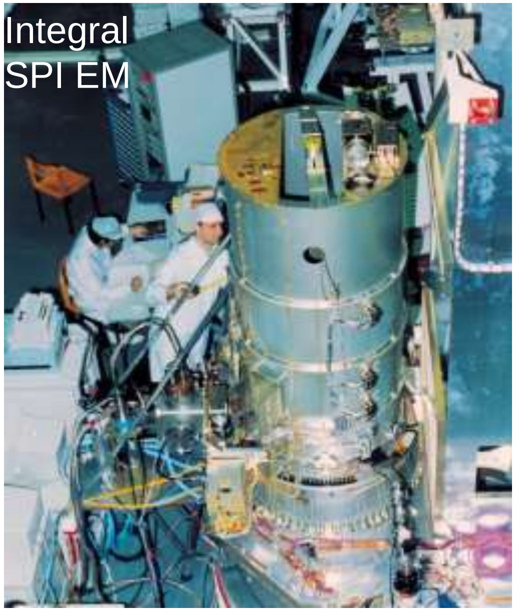
# Cycle of development of a space project

## The « Model philosophy »

In addition, breadboards may be produced very early (phase B) in order to address a specific concern or stringent requirements (e.g. focal plane stucture breadboard to check thermoelastic stability).

Some part of one model may be reused in another one.




# Cycle of development of a space project

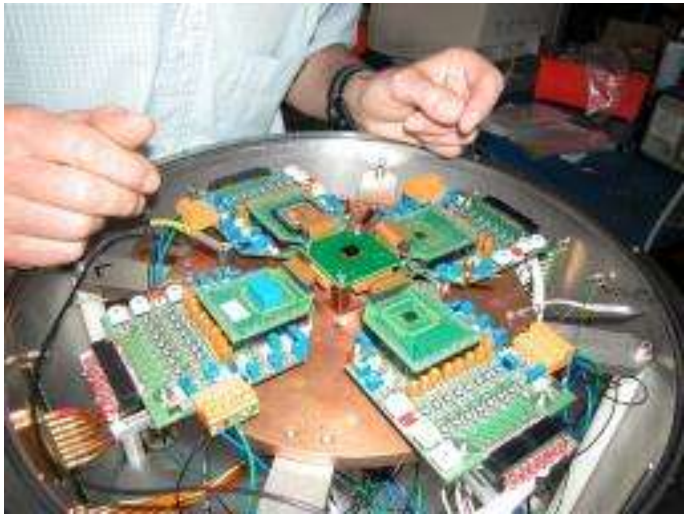
## Research and Development activities

R&D intend to explore and test promising technologies for future missions.

Limited budgets but of primordial importance!

R&D activities are performed in labs, industries or space agencies in parallel to missions development

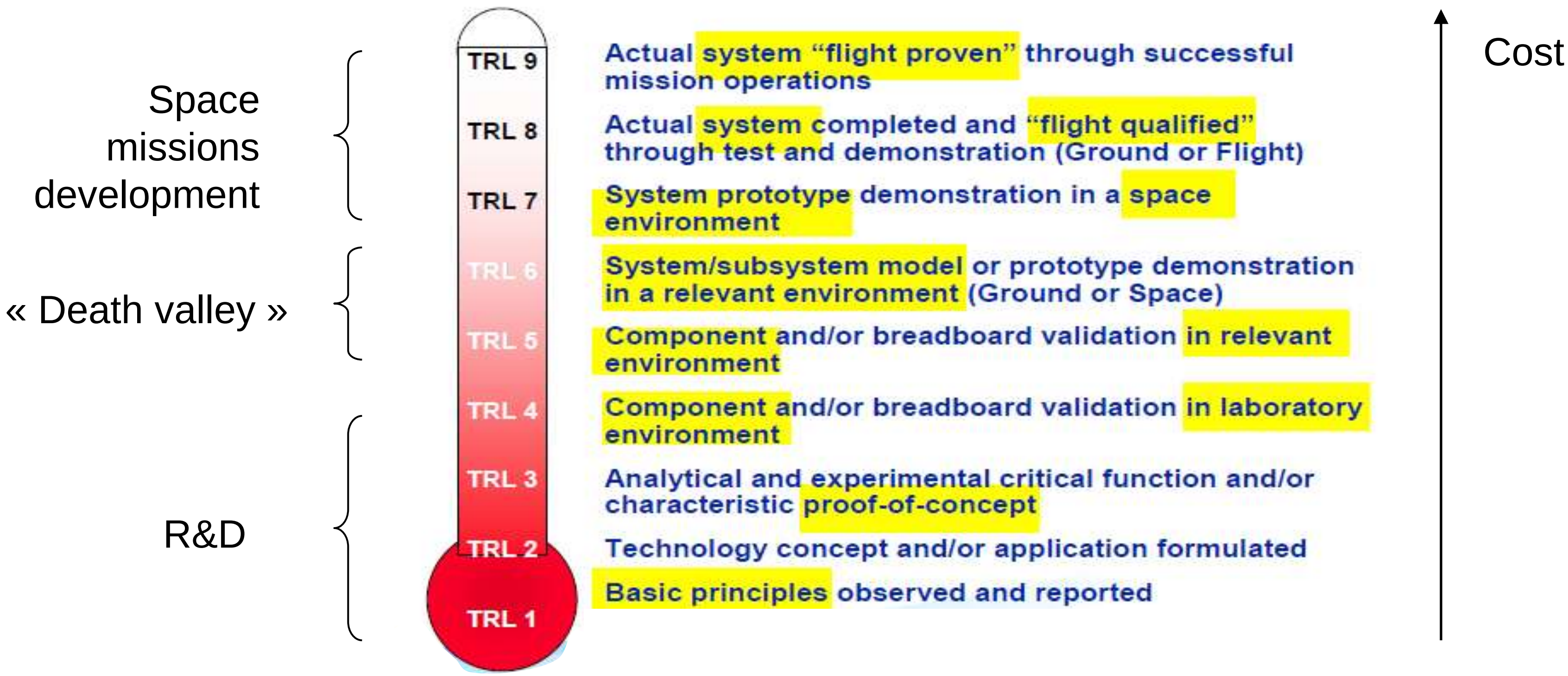
e.g. at CNES R&D's Silicium Compton telescope, hard X-rays detectors, closed-cycle dilution cryogeny… But also R&D's on platforms (materials, telecommunication…), on launchers (hydrodynamics, plasmas…).



# Cycle of development of a space project

Technology Readiness Level

Created by DoD then adopted by most space agencies.
Characterize the level of maturity of a technology/concept towards a space flight.
Used to estimate the levele of risk of a mission and to identify the critical point to adress with a high priority.



# Cycle of development of a space project

## The cost engineery

Space agencies usually compute costs in 2 ways :

- External cost : the « cash » the agency has to pay for a mission (=> laboratory support, industrial contracts…)
- Overall cost : the external cost + the internal agency resources (=> cost of employees, including salaries, taxes, infrastructure…)

In addition, in international collaborations one need to know the overall national cost : it is the agency overall cost + contributions of other institutes (salaries of permanent labs engineers and technicians…).

# And now?

Today the following flying « astroparticles » mission are :
- XMM-Newton (X-ray). Probably up to 2016 at least.
- Chandra (X-ray). Idem
- NuStar (hard X-ray). 2015 at least
- Integral (X-ray and soft gammas). Idem
- Fermi (Gamma) up to 2015 at least
- Swift (Gamma-ray bursts) up to 2015
- AMS-02 (antimatter, neutrino, cosmic rays…) 2020??

What is planned :
- Astro-H (X-ray) 2015
- SVOM (Gama ray-bursts) 2019?
- Euso-balloon (pahtfinder for detection of UHECRs from space) 2014

## And now?

In the US the 2010 « Decadal Survey » issued the following ranking :
- Study of  of dark energy (WFIRST)
- Gravitationnal Waves (LISA)
- X-ray astronomy (IXO)

However budgetary constraints prevent  NASA to start any large project before JWST launch (2018).

In Europe :

X-ray and gravitationnal waves : In 2012 ESA did not select LISA/NGO nor IXO/ATHENA as the next large mission. A new call for 2 « cornerstone » missions (L2&L3, to be launched ~2028 and 2032) will be issued in 2013.

LISA Pathfinder should demonstrate by 2014 some of the technologies on LISA/NGO.

X-ray observatory medium missions will be proposed for the next ESA medium-class call (« M4 », 2014). The European X-ray community is very active but was somehow dispersed on last M call (« M3 », 2010).

Gamma-ray : several concepts are being investigated by labs for MeV astronomy, proposal(s) will be probable at M4 call.

About cosmic rays, the community gathered around the Auger ground project. A proposed next step is Jem-Euso, however programmatic uncertainties (e.g. US participation) have delayed an implementation decision up to now. Launch would not occur before 2017.

**Astroparticles in space has to face harsh competition with cosmological, planetary and exoplanetary missions!**